FUMIGATION, GROSS NITROGEN TRANSFORMATIONS, N-15, NITRATE, RATES, SOIL

1909
Pushnik, J.C., R.S. Demaree, J.L.J. Houpis, W.B. Flory, S.M. Bauer, and P.D. Anderson. 1995. The effect of elevated carbon dioxide on a Sierra-Nevadan dominant species: Pinus ponderosa. *Journal of Biogeography 22(2-3):249-254.*

The impact of increasing atmospheric CO2 has not been fully evaluated on western coniferous forest species. Two year old seedlings of Pinus ponderosa were grown in environmentally controlled chambers under increased CO2 conditions (525 mu L L(-1) and 700 mu L L(-1)) for 6 months. These trees exhibited morphological, physiological and biochemical alterations when compared to our controls (350 mu L L(-1)). Analysis of whole plant biomass distribution has shown no significant treatment effect to the root to shoot ratios. However, while stem diameter and height growth generally increased with elevated CO2, needles exhibited an increased overall specific needle mass and a decreased total needle area. Morphological changes at the needle level included decreased mesophyll to vascular tissue ratio and variations in starch storage in chloroplasts. The elevated CO2 increased internal CO2 concentrations and assimilation of carbon. Biochemical assays revealed that ribulose-bis-phosphate carboxylase (RuBPCase) specific activities increased on per unit area basis with CO2 treatment levels. Sucrose phosphate synthase (SPS) activities exhibited an increase of 55% in the 700 mu L(-1) treatment. These results indicate that the sink-source relationships of these trees have shifted carbon allocation toward above ground growth, possibly due to transport limitations.

KEYWORDS: ATMOSPHERIC CO2, CO2- ENRICHMENT, FORMS, GROWTH, LEAF ANATOMY, PHOTOSYNTHETIC ACCLIMATION, RADIATA, SEEDLINGS, SUCROSE PHOSPHATE SYNTHASE, TREES

1910
Pushnik, J.C., D. Garcia-Ibilcieta, S. Bauer, P.D. Anderson, J. Bell, and J.L.J. Houpis. 1999. Biochemical responses and altered genetic expression patterns in ponderosa pine (Pinus ponderosa Doug ex P. Laws) grown under elevated CO2. *Water, Air, and Soil Pollution 116(1-2):413-422.*

Biochemical and gene expression changes in response to elevated atmospheric CO2 were investigated in five maternal half-sibling breeding families of Ponderosa pine. Seedlings were grown in a common garden located at Lawrence Livermore National Laboratory, in open-topped chambers (OTC) for two years. Chamber atmospheres were maintained at ambient, ambient + 175 mu L L-1, CO2, or ambient + 350 mu L L-1CO2. Growth measurements showed significant increases in stem volumes and volume enhancement ratios in three of the five families studied when grown under elevated CO2. Biochemical and gene expression studies were undertaken to gain a mechanistic understanding of these phenotypic responses. Biochemical studies focused on sucrose phosphate synthase (SPS) specific activities at increase CO2 levels. Kinetic evaluations of SPS showed an increase in V-Max. Specific SPS probes revealed increases in the transcriptional levels of one SPS gene with exposure to increasing CO2. RT-PCR differential gene displays showed that overall only a small fraction of visualized gene transcripts responded to elevated CO2 (8-10%). There were also significant differences between the gene expression patterns of the different families, some of which correlated with alterations in growth at elevated CO2 levels.

KEYWORDS: ALLOCATION, ANATOMY, CARBON-DIOXIDE ENRICHMENT, ENZYMES, LEAVES, METABOLISM, PROTEIN-PHOSPHORYLATION, SEEDLINGS, SUCROSE PHOSPHATE SYNTHASE, TREES

1911
Qi, J.E., J.D. Marshall, and K.G. Mattson. 1994. High soil carbon-dioxide concentrations inhibit root respiration of douglas-fir. *New Phytologist 128(3):435-442.*

Total and basal respiration (R(t) and R(b), respectively) of intact and undisturbed roots of one-year-old Douglas fir seedlings, Pseudotsuga menziesii var. glauca [Beissn] France, were measured at experimentally varied soil carbon dioxide concentrations ([CO2]). Use of specially designed root boxes and a CO2 gas-flow compensating system designed around an infrared gas analyzer (IRGA) allowed controlled delivery of CO2 to roots and simultaneous measurements of CO2 released by roots. Root respiration rate responded to each inlet [CO2], independent of whether the previous concentration had been higher or lower, within two to three hours (paired t test = 0.041, P = 0.622, and n = 13). Total and basal respiration rates decreased exponentially as soil [CO2] rose from 130 ppm, well below atmospheric [CO2], to 7015 ppm, a concentration not uncommon in field soils. Analyses of variance (ANOVA) showed that the effects of soil [CO2] on rates of total and basal root respiration were statistically significant. Root respiration rates decreased by 4 to 5 nmol CO2 g(-1) dry weight of roots s(-1) for every doubling of [CO2] according to the following equations: ln(R(t)) (nmol CO2 g(-1) s(-1)) = 5.24-0.30*ln[CO2] with r = 0.78, P < 0.0001, and n = 70; and ln(R(b)) (nmol CO2 g(-1) s(-1)) = 6.29-0.52*ln[CO2] with r = 0.82, P < 0.0001, and n = 35. The sensitivity of root respiration to [CO2] suggests that some previous laboratory measurements of root respiration at atmospheric [CO2], which is 3 to 10-fold lower than [CO2] in field soils, overestimated root respiration in the field. Further, the potential importance of soil [CO2] indicates that it should be accounted for in models of below-ground carbon budgets.

KEYWORDS: CO2- ENRICHMENT, DARK RESPIRATION, EFFLUX, FIELD, GROWTH, LEAVES, LOLIUM-PERENNE, MAINTENANCE RESPIRATION, PERENNIAL RYEGRASS, SEEDLINGS

1912
Rabbinge, R., H.C. Vanlatesteijn, and J. Goudriaan. 1993. Assessing the greenhouse-effect in agriculture. *Ciba Foundation Symposia 175:62-79.*

Evidence that concentrations of CO2 and trace gases in the atmosphere have increased is irrefutable. Whether or not these increased concentrations will lead to climate changes is still open to debate. Direct effects of increased CO2 concentrations on physiological processes and individual plants have been demonstrated and the consequences for crop growth and production under various circumstances are evaluated with simulation models. The consequences of CO2 enrichment are considerable under optimal growing conditions. However, the majority of crops are grown under sub-optimal conditions where the effects of changes in CO2 are often less. The same holds for the possible indirect effects of environmental changes such as temperature rise. Studies on individual plants under optimal conditions are therefore not sufficient for evaluating the effects at a farm, regional, national or supra-national level. Simulation studies help to bridge the gap between the various aggregation levels and provide a basis for various studies of policy options at various aggregation levels.

KEYWORDS: CARBON DIOXIDE, CO2- ENRICHMENT, GROWTH, PHOTOSYNTHESIS, RESPONSES, SOYBEAN LEAVES, YIELD

1913
Rabha, B.K., and D.C. Uprety. 1998. Effects of elevated CO2 and moisture stress on Brassica juncea. *Photosynthetica 35(4):597-602.*

The interactive effect of elevated CO2 (EC) and moisture stress (MS) on

Brassica juncea cv. Pusa Bold was studied using open- top chambers. The EC markedly increased net photosynthetic rate and internal CO2 concentration and reduced variable and maximal chlorophyll fluorescence. Under MS, EC increased water potential and relative water content, and reduced transpiration rate. The greater allocation of biomass to the roots, which serve as a strong sink for assimilated carbon under EC, helped in better root growth.

KEYWORDS: GROWTH, PHOTOSYNTHESIS, RESPONSES

1914
Raddatz, R.L., and C.F. Shaykewich. 1998. Impact of warm summers on the actual evapotranspiration from spring wheat grown on the eastern Canadian prairies. *Canadian Journal of Soil Science 78(1):171-179.*

How do warm summers (June-July-August) influence the actual evapotranspiration totals from cropped land sown to spring wheat on the eastern Canadian Prairies? The eastern Prairies is a semi-arid region where over 60% of the land is cultivated. Over a third of the cropped land is usually sown to spring wheat. A comparison of mean summer temperatures and modelled evapotranspiration, for the years 1988 to 1996, demonstrated that with the current environmental conditions and farming practices, warm summers have lower actual evapotranspiration totals from spring wheat than cool summers. The average daily actual evapotranspiration rate is generally higher in years with higher mean summer temperatures; however, the crop growth- period is shorter. The net effect is lower total actual evapotranspiration from spring wheat. This suggests that climate warming on the eastern Canadian Prairies, if the current trend continues and all other factors remain equal, will reduce, on average, the total actual evapotranspiration from spring wheat. A reduction in the growth-period actual evapotranspiration from lands sown to spring wheat will likely decrease the total actual evapotranspiration for the entire warm season as growth-period evapotranspiration currently makes up about three-quarters of the seasonal total. However, the magnitude and timing of the reduction is far from certain. The consequence for agriculture may be a reduction in the average spring wheat yield because yield is positively correlated with the actual evapotranspiration total from the crop.

KEYWORDS: AIR CO-2 ENRICHMENT, ENERGY-BALANCE, MODELS, WATER-USE

1915
Radoglou, K.M., P. Aphalo, and P.G. Jarvis. 1992. Response of photosynthesis, stomatal conductance and water-use efficiency to elevated co2 and nutrient supply in acclimated seedlings of phaseolus-vulgaris L. *Annals of Botany 70(3):257-264.*

KEYWORDS: ACCUMULATION, ATMOSPHERIC CARBON-DIOXIDE, ENRICHMENT, GROWTH, INHIBITION, IRRADIANCE, LEAVES, PHOSPHORUS, POPLAR CLONES, RIBULOSE BISPHOSPHATE CARBOXYLASE

1916
Radoglou, K.M., and P.G. Jarvis. 1990. Effects of CO2 enrichment on 4 poplar clones .1. Growth and leaf anatomy. *Annals of Botany 65(6):617-626.*

1917
Radoglou, K.M., and P.G. Jarvis. 1990. Effects of CO2 enrichment on 4 poplar clones .2. Leaf surface- properties. *Annals of Botany 65(6):627-632.*

1918
Radoglou, K.M., and P.G. Jarvis. 1992. The effects of co2 enrichment and nutrient supply on growth- morphology and anatomy of phaseolus-vulgaris L seedlings. *Annals of Botany 70(3):245-256.*

KEYWORDS: AREA, ATMOSPHERIC CARBON-DIOXIDE, FORESTS, LEAF ANATOMY, LEAVES, MINERAL NUTRITION, N,N-DIMETHYLFORMAMIDE, PHOTOSYNTHESIS, PLANTS, POPLAR CLONES

1919
Radoglou, K.M., and P.G. Jarvis. 1993. Effects of atmospheric co2 enrichment on early growth of vivia- faba, a plant with large cotyledons. *Plant, Cell and Environment 16(1):93-98.*

Seedlings of Vicia faba L. were grown in open-top growth chambers at present (P=350 mumol-1) and at elevated (E=700 mumol mol-1) atmospheric CO2 concentration. The effects Of CO2 enrichment on the first phase of growth after germination were examined over 45d. There were no positive effects Of CO2 enrichment on growth of the seedlings during this early phase. No differences were observed in leaf area or in total dry weight. No differences were found in morphology or anatomy of the leaves. The numbers of stomatal and epidermal cells, thickness of leaf, of epidermis and of mesophyll cell-layers were unaffected by CO2 enrichment. Also, no differences were observed in leaf concentrations of chlorophyll, reducing carbohydrates or starch. These results contrast markedly with results from similar experiments on poplar hybrids and Phaseolus vulgaris obtained in the same growth facility. It seems that the intitial growth is under internal control such that the atmospheric CO2 concentration has no effects. The lack of response in this case may be attributed to the presence and longevity of the large cotyledons which provided available substrate for growth.

KEYWORDS: POPLAR CLONES

1920
Rafarel, C.R., T.W. Ashenden, and T.M. Roberts. 1995. An improved Solardome system for exposing plants to elevated CO2 and temperature. *New Phytologist 131(4):481-490.*

Ventilated Solardomes (hemispherical glasshouses) have been used for 20 yr for studying the effects of gaseous pollutants on plants. This paper describes a computer-operated facility for studying the effects of CO2 x temperature regimes on plants. The eight chambers were set up for factorial design experiments - with two levels of CO2 (ambient and ambient+340 ppmv), two levels of temperature (ambient and 3 degrees C tracked continuously above ambient) and two replicates of each CO(2)xtemperature treatment. Monitoring of environmental conditions within the chambers over a 2 yr period has shown highly effective control of CO2 and temperature regimes. Even with high-quality and u.v.-B transmitting glass, the irradiance in the PAR region was reduced by 18 % within the domes. Variation in temperature across the radii of the domes increased with higher photosynthetic photon flux density (PPFD). Vapour pressure deficits (VPDs) in the ambient temperature domes compared well with outside conditions but were higher in the elevated temperature domes. The watering regime within the domes affected intermittently the relationship between 'dome' and 'outside' VPDs. The Solardome facility has been used extensively for studies of the impacts of climate change within the UK Programme on Terrestrial Initiative on Global Environmental Research (TIGER).

KEYWORDS: AIR-POLLUTION, CHAMBERS, ECOSYSTEMS, EXPOSURE, FIELD, OZONE, POLLUTANTS, STRESS, TREES

1921

Raich, J.W., and A. Tufekciogul. 2000. Vegetation and soil respiration: Correlations and controls. *Biogeochemistry 48(1):71-90.*

Soil respiration rates vary significantly among major plant biomes, suggesting that vegetation type influences the rate of soil respiration. However, correlations among climatic factors, vegetation distributions, and soil respiration rates make cause-effect arguments difficult. Vegetation may affect soil respiration by influencing soil microclimate and structure, the quantity of detritus supplied to the soil, the quality of that detritus, and the overall rate of root respiration. At the global scale, soil respiration rates correlate positively with litterfall rates in forests, as previously reported, and with aboveground net primary productivity in grasslands, providing evidence of the importance of detritus supply. To determine the direction and magnitude of the effect of vegetation type on soil respiration, we collated data from published studies where soil respiration rates were measured simultaneously in two or more plant communities. We found no predictable differences in soil respiration between cropped and vegetation-free soils, between forested and cropped soils, or between grassland and cropped soils, possibly due to the diversity of crops and cropping systems included. Factors such as temperature, moisture availability, and substrate properties that simultaneously influence the production and consumption of organic matter are more important in controlling the overall rate of soil respiration than is vegetation type in most cases. However, coniferous forests had similar to 10% lower rates of soil respiration than did adjacent broad-leaved forests growing on the same soil type, and grasslands had, on average, similar to 20% higher soil respiration rates than did comparable forest stands, demonstrating that vegetation type does in some cases significantly affect rates of soil respiration.

KEYWORDS: BOREAL FOREST ECOSYSTEMS, CARBON-DIOXIDE EVOLUTION, CLIMATIC CHANGE, LAND-USE, MAINTENANCE RESPIRATION, NITROGEN MINERALIZATION, PINE PLANTATIONS, PRIMARY PRODUCTIVITY, ROOT RESPIRATION, SEASONAL PATTERN

1922

Raiesi, F.G., and P. Buurman. 1998. Effects of CO2 enrichment on quality of leaf litter and on soil C dynamics in a Mediterranean forest ecosystem. *Fresenius Environmental Bulletin 7(5A-6A):429-436.*

We discuss the effect of long-term elevated CO2 on quality and decomposability of litter from mature trees, and its influence on soil organic matter (SOM) dynamics by evaluating the available data from mineral CO2 springs in Central Italy. Results from the vegetation around these natural CO2 springs demonstrate that elevated CO2 did not affect litter quality. Consequently, C and N mineralization rates remained unaffected by CO2 level. However, there were significant differences in litter quality and decomposition between species. Results from soil analysis indicate that elevated CO2 increased the total organic C content and C pool sizes in the F layer, but not in HA and 0-10 cm layers. Neither were soil N, C/N ratio and the decomposition of SOM affected by elevated CO2. Soil N mineralization in the forest floor seems to be enhanced by CO2 enrichment.

KEYWORDS: ATMOSPHERIC CARBON-DIOXIDE, BIOSPHERE, DECOMPOSITION RATES, ELEVATED CO2, GRASSLAND, RESPONSES

1923

Ranasinghe, S., and G. Taylor. 1996. Mechanism for increased leaf growth in elevated CO2. *Journal of Experimental Botany 47(296):349-358.*

The effect of exposure to elevated CO2 on the processes of leaf cell production and leaf cell expansion was studied using primary leaves of Phaseolus vulgaris L. Cell division and expansion were separated temporally by exposing seedlings to dim red light for 10 d (when leaf cell division was completed) followed by exposure to bright white light for 14 d (when leaf growth was entirely dependent on cell expansion). When plants were exposed to elevated CO2 during the phase of cell expansion, epidermal cell size and leaf area development were stimulated, Three pieces of evidence suggest that this occurred as a result of increased cell wall loosening and extensibility, (i) cell wall extensibility (WEx, measured as tensiometric extension using an Instron) was significantly increased, (ii) cell wall yield turgor (Y, MPa) was reduced and (iii) xyloglucan endotransglycosylase (XET) enzyme activity was significantly increased. When plants were exposed to elevated CO2 during the phase of cell division, the number of epidermal cells was increased whilst final cell size was significantly reduced and this was associated with reduced final leaf area, WEx and XET activity, When plants were exposed to elevated CO2 during both phases of cell division and expansion, leaf area development was not affected. For this treatment, however, the number of epidermal cells was increased, but cell expansion was inhibited, despite exposure to elevated CO2 during the expansion phase. Assessments were also made of the spatial patterns of WEx across the expanding leaf lamina and the data suggest that exposure to elevated CO2 during the phase of leaf expansion may lead to enhanced extensibility particularly at basal leaf margins which may result in altered leaf shape. The data show that both cell production and expansion were stimulated by elevated CO2, but that leaf growth was only enhanced by exposure to elevated CO2 in the cell expansion phase of leaf development. Increased leaf cell expansion is, therefore, an important mechanism for enhanced leaf growth in elevated CO2, whilst the importance of increased leaf cell production in elevated CO2 remains to be elucidated.

KEYWORDS: CELL, ELONGATION, ENRICHMENT, EXPANSION, WALL EXTENSIBILITY, XYLOGLUCAN ENDOTRANSGLYCOSYLASE ACTIVITY

1924

Randerson, J.T., M.V. Thompson, and C.B. Field. 1999. Linking C-13-based estimates of land and ocean sinks with predictions of carbon storage from CO2 fertilization of plant growth. *Tellus Series B-Chemical and Physical Meteorology 51(3):668-678.*

The residence times of carbon in plants, litter, and soils are required for partitioning land and ocean sinks using measurements of atmospheric delta(13)CO(2) and also for estimating terrestrial carbon storage in response to net primary production (NPP) stimulation by elevated levels of atmospheric CO2. While C-13-based calculations of the land sink decline with increasing estimates of terrestrial carbon residence times (through the fossil fuel-induced isotopic disequilibrium term in equations describing the global atmospheric budgets of (CO2)-C-13 and CO2), estimates of land sinks based on CO2 fertilization of plant growth are directly proportional to carbon residence times. Here we used a single model of terrestrial carbon turnover, the Carnegie Ames- Stanford Approach (CASA) biogeochemical model, to simultaneously estimate 1984-1990 terrestrial carbon storage using both approaches. Our goal was to identify the fraction of the (CO2)-C-13-based land sink attributable to CO2 fertilization. Uptake from CO2 fertilization was calculated using a beta factor of 0.46 to describe the response of NPP to increasing concentrations of atmospheric CO2 from 1765 to 1990. Given commonly used parameters in the C-13-based sink calculation and assuming a deforestation flux of 0.8 Pg C/yr, CO2 fertilization accounts for 54% of the missing terrestrial carbon sink from 1984 to 1990. CO2 fertilization can account for all of the missing terrestrial sink only when the terrestrial mean residence time (MRT) and the land isodisequilibrium forcing are greater than many recent estimates.

KEYWORDS: ATMOSPHERIC CO2, C-13, C-13/C-12 RATIO,

DIOXIDE, DISCRIMINATION, ICE CORE, NET PRIMARY PRODUCTION, NITROGEN, SEASONAL CYCLE, TERRESTRIAL BIOSPHERE

1925

Randlett, D.L., D.R. Zak, K.S. Pregitzer, and P.S. Curtis. 1996. Elevated atmospheric carbon dioxide and leaf litter chemistry: Influences on microbial respiration and net nitrogen mineralization. *Soil Science Society of America Journal 60(5):1571-1577.*

Elevated atmospheric CO2 has the potential to influence rates of C and N cycling in terrestrial ecosystems by altering plant litter chemistry and slowing rates of organic matter decomposition, We tested the hypothesis that the chemistry of leaf litter produced at elevated CO2 would slow C and N transformations in soil. Soils were amended with Populus leaf litter produced under two levels of atmospheric CO2 (ambient and twice-ambient) and soil N availability (low and high). Kinetic parameters for microbial respiration and net N mineralization were determined on soil with and without litter during a 32-wk lab incubation, Product accumulation curves for CO2-C and inorganic N were fit to a first order rate equation [y = A(1 - e(-kt))] using nonlinear regression analyses, Although CO2 treatment affected soluble sugar concentration in leaf litter (ambient = 120 g kg(-1), elevated = 130 g kg(-1)), it did not affect starch concentration or C/N ratio, Microbial respiration, microbial biomass, and leaf litter C/N ratio were affected by soil N availability but not by atmospheric CO2, Net N mineralization was a linear function of time and was not significantly different for leaves grown at ambient (50 mg N kg(-1)) and elevated CO2 (35 mg N kg(-1)). Consequently, we found no evidence for the hypothesis that leaf litter produced at elevated atmospheric CO2 will dampen the rates of C and N cycling in soil.

KEYWORDS: CO2, DECOMPOSITION, EFFICIENCY, ENRICHMENT, GROWTH, PRODUCTIVITY, RESPONSES, SEEDLINGS, SOIL-NITROGEN, TERRESTRIAL ECOSYSTEMS

1926

Rao, M.V., and L.J. Dekok. 1994. Interactive effects of high co2 and so2 on growth and antioxidant levels in wheat. *Phyton-Annales Rei Botanicae 34(2):279-290.*

The impact of elevated CO2 and/or SO2 on the growth and antioxidant levels of wheat (Triticum aestivum L. cv. Urban) plants has been studied. High CO2 (0.7 ml l-1) significantly enhanced shoot biomass and photosynthetic capacity, while exposure to SO2 (0.14 mul l-1) resulted in a decreased shoot biomass and in an injured photosynthetic aparatus, illustrated by a loss of chlorophyll and a decreased ratio of variable to maximal fluorescence (F(v)/F(m)) and A(max). However, combined exposure of plants to high CO2 and SO2 eliminated the negative effects of SO2. Sulfate accumulation was almost equal in plants exposed to SO2 and, high CO2 and SO2. A significant increase in ascorbate, glutathione and their redox state was observed in plants exposed to high CO2 and SO2, compared to that of plants exposed to solely SO2. The absence of the negative efects of SO2 in the presence of high CO2 might be related to a high redox state of ascorbate and glutathione. Abbreviations: A(max), maximum rate of oxygen evolution at saturated light and CO2 (mumol m-2 s-1); ASA, reduced ascorbic acid; DHA, dehydroascorbic acid; F(m), maximum emission of photosystem-II chlorophyll fluorescence; F(v), variable component of F(m); GSH, reduced glutathione; GSSG, oxidized glutathione.

1927

Rao, M.V., B.A. Hale, and D.P. Ormrod. 1995. Amelioration of ozone-induced oxidative damage in wheat plants grown under high-carbon dioxide - role of antioxidant enzymes. *Plant Physiology 109(2):421-432.*

O-3-induced changes in growth, oxidative damage to protein, and specific activities of certain antioxidant enzymes were investigated in wheat plants (Triticum aestivum L. cv Roblin) grown under ambient or high CO2. High CO2 enhanced shoot biomass of wheat plants, whereas O-3 exposure decreased shoot biomass. The shoot biomass was relatively unaffected in plants grown under a combination of high CO2 and O-3. O-3 exposure under ambient CO2 decreased photosynthetic pigments, soluble proteins, and ribulose-1,5-bisphosphate carboxylase/oxygenase protein and enhanced oxidative damage to proteins, but these effects were not observed in plants exposed to O-3 under high CO2. O-3 exposure initially enhanced the specific activities of superoxide dismutase, peroxidase, glutathione reductase, and ascorbate peroxidase irrespective of growth in ambient or high CO2. However, the specific activities decreased in plants with prolonged exposure to O-3 under ambient CO2 but not in plants exposed to O-3 under high CO2. Native gels revealed preferential changes in the isoform composition of superoxide dismutase, peroxidases, and ascorbate peroxidase of plants grown under a combination of high CO2 and O-3. Furthermore, growth under high CO2 and O-3 led to the synthesis of one new isoform of glutathione reductase. This could explain why plants grown under a combination of high CO2 and O-3 are capable of resisting O-3-induced damage to growth and proteins compared to plants exposed to O-3 under ambient CO2.

KEYWORDS: AIR- POLLUTANTS, ASCORBATE PEROXIDASE, ATMOSPHERIC CO2 CONCENTRATION, B RADIATION, ELEVATED CO2, ENRICHMENT, PHOTOSYNTHETIC RESPONSE, PROTEINS, SULFUR-DIOXIDE, SUPEROXIDE-DISMUTASE

1928

Rastetter, E.B. 1996. Validating models of ecosystem response to global change. *BioScience 46(3):190-198.*

KEYWORDS: BIOMASS, CARBON BUDGET, CLIMATE, ELEVATED CO2, PHOTOSYNTHESIS, TEMPERATURE, TUNDRA

1929

Rastetter, E.B., and G.R. Shaver. 1992. A model of multiple-element limitation for acclimating vegetation. *Ecology 73(4):1157-1174.*

In this paper we present a simple model of multiple-element limitation of plant production and biomass accumulation. The primary aim of this model is to develop a theoretical framework for examining multiple-element limitation vs. single-element limitation and for examining the relationship between short- term and long-term responses to changes in element availability. In the model we assume that there is an "optimal" ratio of mineral elements in vegetation biomass, and that the vegetation continually adjusts its relative element uptake capacities to compensate for shifts away from this optimum. We examine the responses of this model to changes in element availability in the plant environment, where "availability" is defined either as fixed concentrations of non-depletable elements or as fixed replenishment rates of depletable elements. The model results suggest that the nature of the controls on element availability has a major impact on whether single- or multiple-element limitation prevails, even when plants can acclimate so as to maintain an "optimal" nutritional balance. Single-element limitation occurs when the replenishment rate of an essential element to the available pool is limited and sustainable plant uptake of that element equals the replenishment rate. Furthermore, when single- element limitation prevails, there is little or no correlation between short-term responses to a change in element availability and long-term, equilibrium responses. In general, previous experimental studies and models of plant growth in response to changes in relative availability of multiple, essential elements have either not specified how those resources are controlled, or have examined only one

type of control. Our results help to explain the diversity of results of past studies of multiple-element limitation, suggest some improvements in experimental design for future studies, and have important implications for the extrapolation of the results of controlled experiments to field situations.

KEYWORDS: CO2- ENRICHMENT, COMPETITION, ECOSYSTEMS, EFFICIENCY, GROWTH, NITROGEN-AVAILABILITY, PHOTOSYNTHESIS, PLANTS, TAIGA TREES, TEMPERATURE

1930
Ratanachinakorn, B., A. Klieber, and D.H. Simons. 1997. Effect of short-term controlled atmospheres and maturity on ripening and eating quality of tomatoes. *Postharvest Biology and Technology 11(3):149-154.*

Mature green, breaker, and pink 'Bermuda' tomatoes (Lycopersicon esculentum Mill.) were treated in air, 0.5% O-2 for 1 day, or 80% CO2 for 1 or 2 days at 22 degrees C before ripening in air at 22 degrees C. Headspace ethanol (EtOH) and acetaldehyde (AA), soluble solids (SS), titratable acidity (TA), and pH were measured, and sensory quality was determined using descriptive analysis with a trained panel. Some ripening delay of 1-2 days was observed due to low O-2 and 2 days of high CO2. EtOH and AA production increased more with increasing fruit maturity and with low O-2 at these maturities; both volatiles dissipated to trace amounts before fruit were eating ripe in all treatments. Aroma and taste were not enhanced by any treatment/ripeness combinations, although 80% CO2 for 2 days marginally increased the sweetness and blandness of the fruit. Soluble solids, titratable acidity and pH were not different between treatments or ripening stages. (C) 1997 Elsevier Science B.V.

KEYWORDS: ACETALDEHYDE VAPOR, ANAEROBIC CONDITIONS, EXPRESSION, FRUIT, ORANGES, POSTHARVEST APPLICATION, STORAGE, VOLATILES

1931
Rathgeber, C., J. Guiot, P. Roche, and L. Tessier. 1999. Quercus humilis increase of productivity in the Mediterranean area. *Annals of Forest Science 56(3):211-219.*

Several recent studies have shown an increasing long-term growth trend for various forest tree species in western Europe. Nevertheless such studies have not yet, been performed in Mediterranean Europe. The aim of this work is to analyse changes in productivity of some Mediterranean forest ecosystems compared with other medioeuropean forest ecosystems. Sixteen Quercus humilis (Miller) populations were sampled in south-east France. Tree ring widths were measured for each tree according to three radius, and annual basal area increments were calculated. Two growth indexes (IP and IC) were calculated with two different standardization techniques, in order to remove age and interstation productivity effects. From the IP and IC indexes we can see that there was a productivity increase during the last century, this increase being evaluated at 100 % (IC index). These results indicate that the Mediterranean forest ecosystems have shown a high productivity increase over the last century, as have the medioeuropean forest ecosystems. The best hypothesis to explain this increasing long-term growth trend is a direct CO2 fertilization along with N deposition fertilization. ((C) Inra/Elsevier, Paris.).

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, CLIMATE, ENERGY-PRODUCTION, FERTILIZATION, FOREST ECOSYSTEMS, GROWTH-RESPONSES, NORTHEASTERN FRANCE, TREE-RING CHRONOLOGY, TRENDS

1932
Rattray, E.A.S., E. Paterson, and K. Killham. 1995. Characterization of the dynamics of C-partitioning within lolium-perenne and to the rhizosphere microbial biomass using C-14 pulse-chase. *Biology and Fertility of Soils 19(4):280-286.*

The dynamics of C partitioning with Lolium perenne and its associated rhizosphere was investigated in plant-soil microcosms using C-14 pulse-chase labelling. The CO2(C-14) pulse was introduced into the shoot chamber and the plants allowed to assimilate the label for a fixed period. The microcosm design facilitated independent monitoring of shoot and root/soil respiration during the chase period. Partitioning between above- and below-ground pools was determined between 30 min and 168 h after the pulse, and the distribution was found to vary with the length of the chase period. Initially (30 min after the pulse), C-14 was predominantly (99%) in the shoot biomass and declined thereafter. The results indicate that translocation of recent photoassimilate is rapid, with C-14 detected below ground within 30 min of pulse application. The translocation rate of C-14 below ground was maximal (6.2% h-1) between 30 min and 3h after the pulse, with greatest incorporation into the microbial biomass detected at 3 h. After 3 h, the microbial biomass C-14 pool accounted for 74% of the total C-14 rhizosphere pool. By 24 h, approximately 30% of C-14 assimilate had been translocated below ground; thereafter C-14 translocation was greatly reduced. Partitioning of recent assimilate changed with increasing CO2 concentration. The proportion of C-14 translocated below ground almost doubled from 17.76% at the ambient atmospheric CO2 concentration (450 ppm) to 33.73% at 750 ppm CO2 concentration. More specifically, these changes occurred in the root biomass and the total rhizosphere pools, with two- and threefold C-14 increases at an elevated CO2 concentration compared to ambient, respectively. The pulse- labelling strategy developed in this study provided sufficient sensitivity to determine perturbations in C dynamics in L. perenne, in particular rhizosphere C pools, in response to an elevated atmospheric CO2 concentration.

KEYWORDS: ATMOSPHERIC CO2, CARBON FLOW, FIELD PLOTS, GROWTH-RESPONSE, NITROGEN, PLANTS, ROOTS, SANDY LOAM, SOIL, WHEAT

1933
Raveh, E., M. Gersani, and P.S. Nobel. 1995. Co2 uptake and fluorescence responses for a shade-tolerant cactus hylocereus-undatus under current and doubled co2 concentrations. *Physiologia Plantarum 93(3):505-511.*

Hylocereus undatus (Haworth) Britton and Rose growing in controlled environment chambers at 370 and 740 mu mol CO2 mol(- 1) air showed a Crassulacean acid metabolism (CAM) pattern of CO2 uptake, with 34% more total daily CO2 uptake under the doubled CO2 concentration and most of the increase occurring in the late afternoon. For both CO2 concentrations, 90% of the maximal daily CO2 uptake occurred at a total daily photosynthetic photon flux density (PPFD) of only 10 mol m(-2) day(-1) and the best day/night air temperatures were 25/15 degrees C. Enhancement of the daily net CO2 uptake by doubling the CO2 concentration was greater under the highest PPFD (30 mol m(-2) day(-1)) and extreme day/night air temperatures (15/5 and 45/35 degrees C). After 24 days of drought, daily CO2 uptake under 370 mu mol CO2 mol(-1) was 25% of that under 740 mu mol CO2 mol(-1). The ratio of variable to maximal chlorophyll fluorescence (F-v/F-m) decreased as the PPFD was raised above 5 mol m(-2) day(-1), at extreme day/night temperatures and during drought, suggesting that stress occurred under these conditions. F-v/F-m was higher under the doubled CO2 concentration, indicating that the current CO2 concentration was apparently limiting for photosynthesis. Thus net CO2 uptake by the shade-tolerant H. undatus, the photosynthetic efficiency of which was greatest at low PPFDs, showed a positive response to doubling the CO2 concentration, especially under stressful environmental conditions.

KEYWORDS: AGAVE-VILMORINIANA, CARBON DIOXIDE, CRASSULACEAN ACID METABOLISM, ELEVATED CO2, ENRICHMENT, EXCHANGE, GROWTH, LEAVES, OPUNTIA FICUS INDICA, PLANT

1934

Raven, J.A. 1994. Carbon fixation and carbon availability in marine-phytoplankton. *Photosynthesis Research 39(3):259-273.*

It is widely believed that inorganic C does not limit the rate of short-term photosynthesis, the net productivity, or the maximum biomass, of marine phytoplankton. This lack of inorganic C restriction is less widely believed to hold for phytoplankton in many low alkalinity freshwaters or for seaweed in nutrient-enriched rock pools. These views are examined in the context of the physical chemistry of the inorganic C system in natural waters and of the ways in which various taxa of phytoplankton deal with inorganic C and discriminate between C- 12 and C-13. Using this information to interpret data obtained in the ocean or in freshwater suggests that short-term photosynthesis, production rate, and achieved biomass, of phytoplankton are rarely limited by inorganic C supply but, rather, that the widely suggested factors of limited light, nitrogen or phosphorus supply are the resource inputs which restrict productivity. Global change, by increasing atmospheric CO2 partial pressure and global mean temperatures, is likely to increase the mean CO2 concentration in the atmosphere, but the corresponding change in the oceans will be much less. There are, however, genotypic differences in the handling of inorganic C among the diversity of marine phytoplankton, and in impact on use of limiting nutrients, so increases in the mean CO2 and HCO3- concentrations in surface ocean waters could cause changes in species composition. However, the rarity of inorganic C limitation of marine phytoplankton short-term photosynthesis, net productivity, or the maximum biomass, in today's ocean means that global change is unlikely to increase these three values in the ocean.

KEYWORDS: ATMOSPHERIC CO2, DELTA C 13, GROWTH-RATES, ICE CORE, INORGANIC CARBON, NATURAL ABUNDANCE, PLANTS, PRODUCTIVITY, SURFACE OCEAN, TEMPERATURE

1935

Rawson, H.M. 1992. Plant-responses to temperature under conditions of elevated CO2. *Australian Journal of Botany 40(4-5):473-490.*

A literature survey of the interactive effects of CO2 enrichment and temperature on plant development and growth, indicated that the responses cannot be interpreted within a simple framework. For example, although plant development is generally accelerated by increased temperature, CO2 enrichment can accelerate it even further in some instances, or CO2 enrichment may have neutral or even retarding effects in other cases. Where the temperature and CO2 effects are additive, it is argued that CO2 is operating in the same way as radiation to reduce a carbon limitation. If this were true, CO2 enrichment would be most likely to accelerate development in tropical regions during the low-radiation monsoon season. Similarly, while it would be expected that CO2-enrichment would have increasingly enhancing effects with increasing temperature on phytomass growth, this is not invariably the case. In extreme examples which followed the expected trend, plants grown in twice-normal CO2-enriched atmospheres performed progressively better than those grown at current levels of CO2 by 8.7% for every 1-degrees-C rise in temperature. However, the difference between the two CO2 treatments more commonly increased by only around 2% for every 1-degrees-C rise in temperature. Of examples examined, both sunflower and nodulated cowpea showed the reverse response to temperature, while non-nodulated cowpea, supplied with luxuriant levels of nutrition, showed no interaction with temperature but a strong interaction between CO2 and radiation. Other aspects of the environment such as nutrition and radiation strongly modify the responses to temperature. It is also clear that plant factors such as stage of development can alter the response to CO2. Long-term studies with several species are required which will take into account many environmental variables within a realistic envelope. One methodology for doing this is presented. There was no evidence among species that responses to CO2 arise through any consistent change in morphology such as via increased branching or increased leaf number. Plant plasticity is such that responses can be expressed in a variety of ways determined by other environmental variables.

KEYWORDS: AIR- TEMPERATURE, ATMOSPHERIC CO2, CARBON-DIOXIDE ENRICHMENT, KUDZU PUERARIA-LOBATA, LEAF EXPANSION, SEED YIELD, SPRING WHEAT, WATER-USE, WINTER-WHEAT, YIELD COMPONENTS

1936

Rawson, H.M. 1995. Yield responses of 2 wheat genotypes to carbon-dioxide and temperature in-field studies using temperature-gradient tunnels. *Australian Journal of Plant Physiology 22(1):23-32.*

Clear, plastic-coated, temperature gradient tunnels (TGTs), 8 X 1.25 X 1.25 m were designed and built to examine how temperature and CO2 affect the yield of wheat in the field. Each of the three modules of each TGT was maintained at a different temperature above the ambient temperature using solar heating during the day and electric heating at night. The maximum day-time increment above ambient for the warmest module was 5 degrees C and full-season averages were close to 2 degrees C. TGTs were paired, with air in one being enriched to 700 mu L L(-1) CO2, and in the other being maintained at ambient CO2. Crops were planted in the TGTs at two sites in either summer (December) or winter (April and July) and they remained there until maturity. CO2 enrichment increased the yield in summer plantings by up to 36%. In winter plantings, with mean temperatures between sowing and anthesis of around 10 degrees C, the responses to CO2 were small averaging only 7% (range 1-12%). Though yield declined with increasing temperature in the TGTs in summer, there was a clear trend for an increasing response to CO2 at these higher temperatures, i.e. yield declined less. In summer, there was no convincing evidence for a different relative response to CO2 in two isolines which differed in maturity date, though the later line yielded more under the highest temperature regime (mean of 22- 24 degrees C between sowing and anthesis). In winter there was a strong trend for the isoline requiring less vernalisation to respond more to CO2. It is suggested that early progress towards flowering might predispose wheat to a greater CO2 response. Overall, the data indicated that the positive response to CO2 in grain yield is likely to increase at approximately 1.8% per 1 degrees C in wheat crops that are not limited by water. Extrapolation indicated that the temperature at which there was no response to CO2 was 5 degrees C. All yield responses reflected biomass responses as harvest index was unchanged by CO2.

KEYWORDS: ATMOSPHERIC CO2 ENRICHMENT, CULTIVAR, ELEVATED CO2, PHOTOPERIOD, PHOTOSYNTHESIS, PLANT GROWTH, POA-PRATENSIS, PRODUCTIVITY, STRESS, WATER

1937

Read, J.J., and J.A. Morgan. 1996. Growth and partitioning in Pascopyrum smithii (C-3) and Bouteloua gracilis (C-4) as influenced by carbon dioxide and temperature. *Annals of Botany 77(5):487-496.*

This study investigated how CO2 and temperature affect dry weight (d.wt) accumulation, total nonstructural carbohydrate (TNC) concentration, and partitioning of C and N among organs of two important grasses of the shortgrass steppe, Pascopyrum smithii Rydb. (C-3) and Bouteloua gracilis (H.B.K.) Lag. ex Steud. (C-4). Treatment combinations comprised two temperatures (20 and 35 degrees C) at two

concentrations of CO2 (380 and 750 mu mol mol(-1)), and two additional temperatures of 25 and 30 degrees C at 750 mu mol mol(-1) CO2. Plants were maintained under favourable nutrient and soil moisture and harvested following 21, 35, and 49 d of treatment. CO2-induced growth enhancements were greatest at temperatures considered favourable for growth of these grasses. Compared to growth at 380 mu mol mol(-1) CO2, final d.wt of CO2-enriched P. smithii increased 84% at 20 degrees C but only 4% at 35 degrees C. Final d.wt of B. gracilis was unaffected by CO2 at 20 degrees C, but was enhanced by 28% at 35 degrees C. Root:shoot ratios remained relatively constant across CO2 levels, but increased in P. smithii with reduction in temperature. These partitioning results were adequately explained by the theory of balanced root and shoot activity. Favourable growth temperatures led to CO2-induced accumulations of TNC in leaves of both species, and in stems of P. smithii, which generally reflected responses of above-ground d.wt partitioning to CO2. However, CO2-induced decreases in plant tissue N concentrations were more evident for P. smithii. Roots of CO2-enriched P. smithii had greater total N content at 20 degrees C, an allocation of N below- ground that may be an especially important adaptation for C-3 plants. Tissue N contents of B. gracilis were unaffected by CO2. Results suggest CO2 enrichment may lead to reduced N requirements for growth in C-3 plants and lower shoot N concentration, especially at favourable growth temperatures. (C) 1996 Annals of Botany Company

KEYWORDS: ATMOSPHERIC CO2 CONCENTRATIONS, BIOMASS, ENRICHMENT, MODEL, NITROGEN, RESPONSES

1938

Read, J.J., J.A. Morgan, N.J. Chatterton, and P.A. Harrison. 1997. Gas exchange and carbohydrate and nitrogen concentrations in leaves of Pascopyrum smithii (C-3) and Bonteloua gracilis (C-4) at different carbon dioxide concentrations and temperatures. *Annals of Botany 79(2):197-206.*

Pascopyrum smithii (C-3) and Bouteloua gracilis (C-4) are important forage grasses native to the Colorado shortgrass steppe. This study investigated photosynthetic responses of these grasses to long-term CO2 enrichment and temperature in relation to leaf nonstructural carbohydrate (TNC) and [N]. Glasshouse-grown seedlings were transferred to growth chambers and grown for 49 d at two CO2 concentrations (380 and 750 mu mol mol(-1)) al 20 and 35 degrees C, and two additional temperatures (25 and 30 degrees C) at 750 mu mol mol(-1) CO2. Leaf CO2 exchange rate (CER) was measured at a plant's respective growth temperature and at two CO2 concentrations of approx. 380 and 700 mu mol mol(-1). Long-term CO2 enrichment stimulated CER in both species, although the response was greater in the CER P. smithii. Doubling the [CO2] from 380 to 750 mu mol mol(-1) stimulated CER of P. smithii slightly more in plants grown and measured al 30 degrees C compared to plants grown at 20, 25 or 35 degrees C. CO2-enriched plants sometimes exhibited lower CER when compared to ambient-grown controls measured at the same [CO2], indicating photosynthetic acclimation to CO2 growth regime. In P. smithii, such reductions in CER were associated with increases in TNC and specific leaf mass, reductions in leaf [N] and, in one instance, a reduction in leaf conductance compared to controls. In B. gracilis, photosynthetic acclimation was observed more often, but significant changes in leaf metabolite levels from growth at different [CO2] were generally less evident. Temperatures considered optimal for growth (C-3: 20 degrees C; C-4: 35 degrees C) sometimes led to CO2-induced accumulations of TNC in both species, with starch accumulating in the leaves of both species, and fructans accumulating only in P. smithii. Photosynthesis of both species is likely to be enhanced in future CO2-enriched and warmer environments, although responses will sometimes be attenuated by acclimation. (C) 1997 Annals of Botany Company.

KEYWORDS: ACCLIMATION, ACCUMULATION, ATMOSPHERIC CO2 CONCENTRATIONS, BOUTELOUA-GRACILIS, COOL TEMPERATURES, ELEVATED CO2, GROWTH, PHOTOSYNTHESIS, PLANTS, STARCH

1939

Reddy, A.R., K.R. Reddy, and H.F. Hodges. 1998. Interactive effects of elevated carbon dioxide and growth temperature on photosynthesis in cotton leaves. *Plant Growth Regulation 26(1):33-40.*

Cotton (Gossypium hirsutum L., cv DPL 5415) plants were grown in naturally lit environment chambers at day/night temperature regimes of 26/18 (T26/18), 31/23 (T-31/23) and 36/28 degrees C (T-36/28) and CO2 concentrations of 350 (C-350), 450 (C-450) and 700 IA L L-1 (C-700). Net photosynthesis rates, stomatal conductance, transpiration, RuBP carboxylase activity and the foliar contents of starch and sucrose were measured during different growth stages. Net CO2 assimilation rates increased with increasing CO2 and temperature regimes. The enhancement of photosynthesis was from 24 mu mol CO2 m(-2) s(-1) (with C-350 and T-26/18) to 41 mu mol m-2 s(-1) (with C-700 and T-36/28). Stomatal conductance decreased with increasing CO2 while it increased up to T-31/23 and then declined. The interactive effects of CO2 and temperature resulted in a 30% decrease in transpiration. Although the leaves grown in elevated CO2 had high starch and sucrose concentrations, their content decreased with increasing temperature. Increasing temperature from T- 26/18 to 36/28 increased RuBP carboxylase activity in the order of 121, 172 and 190 mu mol mg(-1) chi h(-1) at C-350, C-450 and C-700 respectively. Our data suggest that leaf photosynthesis in cotton benefited more from CO2 enrichment at warm temperatures than at low growth temperature regimes.

KEYWORDS: ACCLIMATION, ACTIVATION, ATMOSPHERIC CO2, ENRICHMENT, PLANTS, PROTEIN, RATES, RICE

1940

Reddy, K.R., G.H. Davidonis, A.S. Johnson, and B.T. Vinyard. 1999. Temperature regime and carbon dioxide enrichment alter cotton roll development and fiber properties. *Agronomy Journal 91(5):851-858.*

Temperature and atmospheric carbon dioxide concentration [CO2] affect cotton (Gossypium hirsutum L.) growth and development, but the interaction of these two factors on boil and fiber properties has not been studied. An experiment aas conducted in naturally lit plant growth chambers to determine the influence of temperature and atmospheric [CO2] on cotton (cv. DPL-51) boll and fiber growth parameters. Five temperature regimes were evaluated: the 1995 temperature at Mississippi State, MS; the 1995 temperature minus 2 degrees C; and the 1995 temperature plus 2, 5, and 7 degrees C. Daily and seasonal variation and amplitudes were maintained. Atmospheric [CO2] treatments were 360 (ambient) and 720 mu L L-1. Boll number, bell growth, and fiber properties were measured. Boll size and maturation periods decreased as temperature increased. Boll growth increased with temperature to 25 degrees C and then declined at the highest temperature. Boll maturation period, size, and growth rates were not affected by atmospheric [CO2]. The most temperature-sensitive aspect of cotton development is boll retention. Almost no bells were retained to maturity at 1995 plus 5 or 7 degrees C, but squares and bells were continuously produced even at those high temperatures. Therefore, the upper limit for cotton boil survival is 32 degrees C, or 5 degrees C warmer than the 1995 U.S. Mid-South ambient temperatures. The 720 mu L L-1 atmospheric [CO2] had about 40% more squares and bells across temperatures than the 360 mu L L-1 [CO2], Fibers were longer when bells grew at less than optimal temperatures (25 degrees C) for boll growth. As temperature increased, fiber length distributions were more uniform. Fiber fineness and maturity increased linearly with the increase in temperature up to 26 degrees C, but decreased at 32 degrees C. Short-fiber content declined linearly from 17 to 26 degrees C, but was higher at higher temperature.

As for boll growth and developmental parameters, elevated atmospheric [CO2] did not affect any of the fiber parameters. Changes in temperature, however, had a dramatic effect on boll set and tiber properties. The relationships between temperature and boll growth and developmental rate functions and fiber properties provide the necessary functional parameters to build fiber models under optimum water and nutrient conditions.

KEYWORDS: CROP MANAGEMENT, GROWTH, RAY-FLUORESCENCE SPECTROSCOPY, RICE, SIMULATION-MODEL, SYSTEM

1941

Reddy, K.R., H.F. Hodges, and J.M. McKinion. 1995. Carbon-dioxide and temperature effects on pima cotton development. *Agronomy Journal 87(5):820-826.*

Predicting plant responses to changing atmospheric CO2 and to the possible global warming are important concerns. Effects of CO2 on developmental events are poorly documented, as is the interaction of CO2 and other major climate variables on crop development. The objective of this experiment was to determine the effects of an altered CO2 environment and interactions of CO2 and temperature on pima cotton developmental rates. Pima cotton (Gossypium barbadense L. cv. S-6) was grown from seed in sun-lit plant growth chambers. Air temperatures were controlled from 20/12 to 40/32 degrees C (day/night) in 5-degree increments. Daytime CO2 was maintained at 350 or 700 mu L L(- 1). In a second experiment, the temperature was maintained at 30/22 degrees C day/night and the plants were grown in 350, 450, or 700 mu L L(-1) CO2. Days required to develop nodes on the mainstem, days from emergence to first square, number of vegetative and fruiting branches, number of fruiting sites produced, number of bells and squares produced, and number of bells and squares retained by the plants were determined. Rates of mainstem node formation and the time required to produce the first square and first flower were not sensitive to atmospheric CO2, but were very sensitive to temperature. Prefruiting branch nodal positions required longer to develop than nodes with fruiting branches. Carbon dioxide levels did not affect the time required to produce nodes. Number of branches produced was sensitive to both temperature and CO2. The larger number of bells set on the lower branches of plants grown at high CO2 provided a larger sink for photosynthate than plants grown at low CO2. This may be the reason for the observed reduction in number of fruit at the upper nodes of high-CO2-grown plants. More bells and squares were produced and retained on plants grown in high-CO2 environments, except that none were produced in either CO2 environment at 40/32 degrees C. Our results indicate that high-temperature-tolerant cotton cultivars would be more productive in the present-day CO2 world, and they would be essential in the future if global temperature increases.

KEYWORDS: ELEVATED CO2, ENRICHMENT, GROWTH, PLANTS, RESPONSES

1942

Reddy, K.R., H.F. Hodges, and J.M. McKinion. 1995. Carbon-dioxide and temperature effects on pima cotton growth. *Agriculture Ecosystems & Environment 54(1-2):17-29.*

Temperature and CO2 are major environmental variables that affect plant growth and development. Limited information is available concerning how these factors affect plants, as well as specific interactions between the two. We conducted two experiments in controlled environmental chambers were temperature and CO2 were controlled and other environmental factors were not limiting. The purpose was to determine how cotton grew and responded to a range of temperatures and CO2 concentrations. During vegetative development, stem growth was quite sensitive to CO2 resulting in more effective early-season light capture. Plants did not develop more nodes when exposed to additional CO2, while node number increased more at higher temperatures. Individual leaf growth was about 18% greater at optimum temperature in 450 mul 1(-1) than in 350 mul 1(-1) CO2, but did not increase from 450 mul 1(-1) CO2 to 700 mul 1(-1) CO2. However, the time required for a leaf to reach mature size was not influenced by CO2. Leaf area, on the whole plant basis, was about 33% greater on plants grown at optimum temperature in high CO2 than in ambient CO2. The greater leaf area on a whole plant basis was achieved by a combination of larger leaves and additional leaves produced primarily on the branches. There was a 28% increase in number of bolls produced at 700 mul 1(-1) CO2 at optimum temperature compared with bolls produced at 350 mul 1(-1) CO2. There was not, however, an increase in boll size due to high CO2. At 35.5-degrees-C, little growth response to high CO2 environments occurred at 700 mul 1(-1) CO2 compared with 350 mul 1(-1) CO2, but approximately a 45% increase occurred in the plants grown at 18.9-26.9-degrees-C. Less total biomass was produced at 35.5-degrees-C than at 26.9-degrees-C and no bolls were produced in either CO2 environment at the higher temperature. The most important response to temperature and CO2 occurred at high temperatures where the effects of elevated CO2 on plant growth were masked by apparent high-temperature injury that limited growth of all plant organs, particularly, reproductive growth.

KEYWORDS: ELEVATED CO2, RESPONSES, RETENTION

1943

Reddy, K.R., H.F. Hodges, and J.M. McKinion. 1997. A comparison of scenarios for the effect of global climate change on cotton growth and yield. *Australian Journal of Plant Physiology 24(6):707-713.*

If global surface temperatures change as projected because of radiative and physiological effects of a changing environment, we should expect important changes in crop production in the 21st Century. Experiments were conducted at ambient and twice ambient atmospheric CO2 concentrations at five temperatures. The 1995 temperature in Mississippi was used as a reference with the other temperatures being 1995 minus 2 degrees C, and 1995 plus 2, 5 and 7 degrees C. Daily and seasonal variation and amplitudes were maintained. Seedlings had 4-6 times as much leaf area and dry weight at 20 d after emergence when grown at 28 degrees C as at 23 degrees C (1995 ambient) average temperature during that growth period. Number of days to first square, flower, and open boil decreased as temperature increased. Double atmospheric CO2 did not affect these developmental rates. Temperatures above 28 degrees C, or 1995 average whole-season temperatures, were detrimental to mid-and late-season boil retention and growth. No fruits were retained to maturity at 1995 plus 5 or 7 degrees C. However, whole season vegetative growth was not significantly reduced by temperature 5-7 degrees C above the 1995 ambient conditions. Twice ambient CO2 caused about 40% increase in vegetative dry matter accumulation across temperatures. In a separate experiment, similar results were obtained on fruiting cotton grown at a range of temperatures based on long-term average US Midsouth July temperatures. Therefore, if global warming occurs as predicted, food and fibre production in such high- temperature and humid environments may be more limited to vegetative structures and the animals that consume vegetative structures.

KEYWORDS: ATMOSPHERIC CO2, CARBON-DIOXIDE ENRICHMENT, PIMA COTTON, RESPONSES, RICE

1944

Reddy, K.R., H.F. Hodges, and J.M. McKinion. 1997. Modeling temperature effects on cotton internode and leaf growth. *Crop Science 37(2):503-509.*

Cotton (Gossypium hirsutum L.) is grown commercially in temperatures that vary greatly during the season. The purpose of this study was to develop potential growth and developmental rates of cotton leaves and internodes as a function of temperature in a temperature-limiting environment. That information may be used with growth duration and appropriate stress factors to develop a crop canopy development model. Plants were grown in sunlit plant growth chambers in five temperatures, 20/12 degrees C to 40/32 degrees C (day/night), at ambient (350 mu L L-1 CO2) and twice ambient carbon dioxide levels in well-watered and fertilized conditions. Plants were monitored daily for leaf unfolding dates, areas of leaves, and lengths of internodes at leaf unfolding, and growth of leaves and internodes. Durations of leaf and internode expansion were also determined. Leaf unfolding interval rates of both mainstem and fruiting branches increased as temperature increased; the rate of mainstem leaf unfolding interval increased more than the rate of branch leaf unfolding. Irrespective of sizes, leaves, and internodes fit a single relationship of relative expansion rates and age for each temperature condition. Enriching CO2 to twice the ambient level did not change these relationships. Increasing temperature increased maximum growth rate, decreased the decay in the rate of expansion due to age, and reduced growth duration of both leaves and internodes. Internodes typically took less time than leaves to elongate at all temperatures. Leaf area and internode length at leaf unfolding increased as temperature increased to 27 to 30 degrees C, then decreased at higher temperatures.

KEYWORDS: CARBON DIOXIDE, GOSSYPIUM HIRSUTUM L, INITIATION, LEAVES, YIELD

1945
Reddy, K.R., R.R. Robana, H.F. Hodges, X.J. Liu, and J.M. McKinion. 1998. Interactions of CO2 enrichment and temperature on cotton growth and leaf characteristics. *Environmental and Experimental Botany 39(2):117-129.*

Studies on the interactive effects of atmospheric CO2 and temperature on growth and leaf morphology, particularly on stomatal index and density are limited. Upland cotton was grown in naturally-lit plant growth chambers al 30/22 degrees C day/night temperatures from planting until squaring or the fifth or sixth leaf emerged. Five growth chambers were maintained at ambient (350 mu l l(-1)) CO2 and another five at twice ambient (700 mu l l(-1)) CO2 throughout the experiment. Day/night temperature treatments of 20/12, 25/17, 30/22, 35/27 and 40/32 degrees C were imposed at each CO2 treatment for 42 days after squaring. The plants were irrigated with half- strength Hoagland's nutrient solution three times per day. Growth of plant parts was determined at the end of the experiment. Stomatal characteristics, nonstructural carbohydrates and specific leaf weight were measured on the fully expanded tenth mainstem leaf, Stomatal density and index were not affected by elevated CO2. Stomata and epidermal cell numbers pet leaf increased in high CO2 and were positively correlated with final leaf sizes irrespective of CO2 level. Our results suggest that plants do not acclimate to elevated CO2 by changing stomatal density within a single generation. Leaves had greater area and accumulated more biomass when grown in high CO2. Growth stimulation expressed as dry weight at 700 mu l l(-1) over dry weight al 350 mu l l(-1) CO2 was uniform across temperatures. Temperature optimum for vegetative and reproductive growth was 30/22 degrees C and was not altered by CO2 enrichment. Fruit retention was severely curtailed at the two higher temperatures compared to 30/22 degrees C in both CO2 environments. increased carbohydrate storage in leaves may be an added advantage for initiation and growth of vegetative structures such as branches at all temperatures. However, it is unlikely that high temperature effects on flower abortion will be ameliorated by high CO2. Species/cultivars that retain fruits at high temperatures would be more productive both in the present-day cotton producing environments and are even more desirable in the future warmer world.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, CLIMATE SENSITIVITY, ELEVATED CO2, INCREASES, LEAVES, PIMA COTTON, PLANTS, RESPONSES, STOMATAL DENSITY

1946
Reddy, S.R.C., and C. Price. 1999. Carbon sequestration and conservation of tropical forests under uncertainty. *Journal of Agricultural Economics 50(1):17-35.*

Concern for global warming has focused attention on the rob of tropical forests in the reduction of ambient CO2 levels and mitigation of climate change. Deforestation is a major land use change in the tropics, with forest resources undergoing degradation through the influence of logging and conversion to other uses. Land use change is a product of varied local and regional resource use policies. Management of forest resources is one such major temporal factor, influencing resource stability and the carbon pool. Under a given management policy, both the long period of forest growth, and the slow turnover and decay of the carbon pool, enhance the relevance of stand level management policies as cost-effective mechanisms mitigating climate change. Apart from regional level uncertainties like the nature of land use and the estimation of carbon storage in vegetation and soil, the carbon flux of tropical forests is greatly influenced by uncertainty in regenerative capacity of forests and in harvest and management policies. A case study from India is used to develop a transition matrix model of natural forest management, and to explore the economic implications of maintaining and expanding existing carbon sinks. The study further explores the significance of investments in additional carbon sink in plantation forests, given continued uncertainty in natural forest management.

KEYWORDS: BIOMASS, CLIMATE, DAMAGE, LAND, MANAGEMENT, SOUTHEAST-ASIA, STORAGE, TRANSITION

1947
Reddy, V.R., K.R. Reddy, and B. Acock. 1995. Carbon-dioxide and temperature interactions on stem extension, node initiation, and fruiting in cotton. *Agriculture Ecosystems & Environment 55(1):17-28.*

Understanding the response of agricultural crops to rising carbon dioxide concentration (CO2) and temperature is critical for modeling the effects of future climate change on crop productivity. The objective of this study was to evaluate the direct and interactive effects of temperature and CO2 on mainstem and branch expansion rates, node initiation rates, and fruiting in cotton to be used for the development of a cotton simulation model. Cotton plants (Gossypium hirsutum L., cv. DPL 50) were grown in plant growth chambers exposed to natural light levels with temperature and C4 as treatments. The average temperatures were 17.8, 18.7, 22.7, 26.6, and 30.6 degrees C during a 70 day experimental period with CO2 treatments of 350 and 700 mu l l(-1) at each temperature. Plant height and number of mainstem nodes increased with increase in temperature and CO2. A nine-fold increase was observed in number of fruiting branches with increase in temperature from 17.8 to 30.6 degrees C, however, no significant differences were observed in fruiting branch number due to doubling of CO2 except at 30.6 degrees C. The number of days from emergence to first square was strongly influenced by temperature, and CO2 had no effect on this process. The number of squares and bells were increased at higher temperatures, and the rate of increase was greater at 700 mu l l(-1) CO2.

KEYWORDS: AIR- TEMPERATURE, ATMOSPHERIC CO2 ENRICHMENT, GROWTH, PHOTOSYNTHESIS, SOYBEAN CANOPIES, TRANSPIRATION RESPONSES, YIELD

1948
Reddy, V.R., K.R. Reddy, and H.F. Hodges. 1995. Carbon-dioxide

enrichment and temperature effects on cotton canopy photosynthesis, transpiration, and water-use efficiency. *Field Crops Research 41(1):13-23.*

The objectives of this study were to evaluate effects of ambient and double ambient [CO2] at a range of growing temperatures on photosynthesis, respiration, transpiration, water-use efficiency and dry matter accumulation of cotton plants (Gossypium hirsutum L., cv. DPL 50). In Experiment I, plants were grown outdoors until first bloom, then transferred into naturally lit growth chambers and grown for 22 days at 30/ 18 degrees C with five CO2 concentrations varying from 350 to 900 mu l l(-1). In Experiment II, air temperatures were maintained at 20/12, 25/17, 30/22, and 35/27 degrees C day/night during a 70-day experimental period with [CO2] of 350 and 700 mu l l(-1) at each temperature, Photosynthesis increased with [CO2] from 350 to 700 mu l l(-1) and with temperature. Plants grown at 35/27 degrees C produced fewer bells due to abscission compared with plants grown at optimum temperatures (30/20 degrees C). At higher [CO2], water-use efficiency increased at all temperatures due mainly to increased canopy photosynthesis but also to more limited extent to reduced canopy transpiration. Increased photosynthesis at higher [CO2] resulted in greater dry matter accumulation at all temperatures except at 20/12 degrees C. Respiration increased as dry matter and temperature increased. Plants grown at higher [CO2] had less respiration per unit dry matter but more per unit area. These results indicate that future increases in [CO2] are likely to benefit cotton production by increasing carbon assimilation under temperatures favorable for cotton growth. Reduced fruit weights at higher temperatures indicate potential negative effects on production if air temperatures increase as projected in a high-CO2 world.

KEYWORDS: CLIMATE, CO2, CROP YIELD, GROWTH, LEAVES, RESPIRATION, RESPONSES, SIMULATION

1949

Reddy, V.R., K.R. Reddy, and Z. Wang. 1997. Cotton responses to nitrogen, carbon dioxide, and temperature interactions (Reprinted from Plant nutrition for sustainable food production and environment, 1997). *Soil Science and Plant Nutrition 43:1125-1130.*

Several studies were conducted to evaluate how increases in the global atmospheric carbon dioxide concentration [CO2] and temperature affect growth and development rates, dry matter production, photosynthesis, and water use efficiency of cotton and how these responses are influenced by leaf N levels. In one study, cotton (cv. DPL 50) plants were grown at four temperatures (20/12, 25/17, 30/22, and 35/27 degrees C day/night) until harvest at 70 days after emergence (DAE). Each temperature treatment was combined with [CO2] of 350 or 700 mu L L-1. In another study, cotton (cv. DES 119) grown at two [CO2] received five N treatments (0, 1, 2, 6, and 10 mM NO3 in Hoagland's nutrient solution) at 17 DAE and every 2 days thereafter. Canopy gross photosynthetic rates increased with increasing [CO2] and temperature. The increased photosynthesis resulted in higher plant growth and dry matter accumulation rates except at the highest temperature. At 70 DAE, the maximum canopy dry matter accumulation rate occurred in 30/22 degrees C. The 35/27 degrees C treatment induced fruit abortion, resulting in greater dry matter accumulation in vegetative structures. Increases in plant dry weights by CO2 enrichment were greater in the two high temperature regimes than in the two lower temperature regimes. Water-use efficiency increased with increased [CO2] and decreased with increased temperature. Increases in water-use efficiency were due mainly to increased photosynthesis and partly to reduced canopy transpiration. Increase in leaf N concentration increased cotton photosynthesis and vegetative growth rates, and the increases were higher at 700 mu L L-1 than at 350 mu L L-1 [CO2].

KEYWORDS: CANOPY PHOTOSYNTHESIS, CROP YIELD, DEFICIENCY, ENRICHMENT, TRANSPIRATION, USE EFFICIENCY, WATER RELATIONS

1950

Reece, C.F., S.V. Krupa, H.J. Jager, S.W. Roberts, S.J. Hastings, and W.C. Oechel. 1995. Evaluating the effects of elevated levels of atmospheric trace gases on herbs and shrubs - a prototype dual array field exposure system. *Environmental Pollution 90(1):25-31.*

In the context of global climate change, an understanding of the long-term effects of increasing concentrations of atmospheric trace gases (carbon dioxide, CO2, ozone, O-3, oxides of nitrogen, NOx etc.) on both cultivated and native vegetation is of utmost importance. Over the years, under field conditions, various trace gas-vegetation exposure methodologies with differing advantages and disadvantages have been used. Because of these variable criteria, with elevated O-3 or CO2 levels, at the present time the approach of free-air experimental-release of the gas into study plots is attracting much attention. However, in the case of CO2, this approach (using 15 m diameter study plot with a single circular array of vent pipes) has proven to be cost prohibitive (about $59000- 98000/year/replicate) due to the consumption of significant quantities of the gas to perform the experiment (CO2 level elevated to 400 ppm above the ambient). Therefore, in this paper, we present a new approach consisting of a dual concentric exposure array of vertical risers or vent pipes. The purpose of the outer array (17 m diameter) is to vent ambient air outward and toward the incoming wind thus providing an air curtain to reduce the velocity of that incoming wind to simulate the mode or the most frequently occurring wind speed at the study site. The inner array (15 m diameter) vents the required elevated levels of trace gases (CO2, O-3, etc.) into the study plot. This dual array system is designed to provide spatial homogeneity (shown through diffusion modeling) of the desired trace-gas levels within the study plot and to also reduce its consumption. As an example, while in the single- array free-air CO2-release system the consumption of CO2 to elevate its ambient concentration by 400 ppm is calculated to be about 980 tons/year/replicate, it is estimated that in the dual array system it would be approximately 590 tons/year/replicate. Thus, the dual array system may provide substantial cost savings ($24000-39000/year/replicate) in the CO2 consumption ($60-100/ton of CO2) alone. Similarly, benefits in the requirements of other trace gases (O-3, NOx, etc.) are expected, in future multivariate studies on global climate change.

KEYWORDS: AIR, ENRICHMENT

1951

Reekie, E.G., and F.A. Bazzaz. 1991. Phenology and growth in 4 annual species grown in ambient and elevated co2. *Canadian Journal of Botany-Revue Canadienne De Botanique 69(11):2475-2481.*

The objectives of this study were (i) to test the hypothesis that changes in phenology with CO2 are a function of the effect of CO2 upon growth and (ii) to determine if CO2-induced changes in phenology can influence competitive outcome. We examined the effect of 350, 525, and 700-mu-L.L-1 CO2 on Guara brachycarpa, Gailardia pulchella, Oenothera laciniata, and Lupinus texensis. Plants were grown as individuals in 150-, 500-, or 1000-mL pots and in competition in 1000-mL pots. Growth and development were monitored at twice-weekly intervals, by recording the number of leaves and noting the presence or absence of stem elongation, branching, flower buds, and open flowers. Elevated CO2 affected both growth and phenology, but the direction and magnitude of effects varied with species and soil volume. Elevated CO2 did not appear to affect development through its effect on growth. Those treatments in which there were significant effects of CO2 on growth were generally different from those treatments in which CO2 affected phenology. Rather than affecting phenology by changing plant size, CO2 appeared to affect phenology by modifying the size at which plants

switched from one stage to the next. The level of CO2 changed competitive outcome; the importance of Lupinus increased whereas that of Oenothera decreased with increased CO2. These changes were more closely related to the effect of CO2 on growth than its effect on phenology.

KEYWORDS: CARBON DIOXIDE, FATE, PHARBITIS, PREDICTIONS, ROSETTE SIZE

1952

Reekie, E.G., C. MacDougall, I. Wong, and P.R. Hicklenton. 1998. Effect of sink size on growth response to elevated atmospheric CO2 within the genus Brassica. *Canadian Journal of Botany-Revue Canadienne De Botanique 76(5):829-835.*

Many plants grown at elevated CO2 concentrations exhibit enhanced photosynthetic rates. However, this increase in photosynthesis is often reduced after prolonged exposure to elevated CO2. This reduction may be related to the capacity of plants to utilize the extra photosynthate produced at elevated CO2. This study examined the effect of source to sink ratio on the capacity of plants to respond to elevated CO2. Seven species or cultivars within the genus Brassica were germinated and grown at either 350 or 1000 ppm CO2. Broccoli (Brassica oleracea L.) and cauliflower (B. oleracea L.) have large carbon sinks in the reproductive structures; Chinese broccoli (Brassica campestris L.) and marrow stem kale (B. oleracea) have carbon sinks in the stem; turnip (B. campestris) stores carbon in the root; rape (Brassica napus L.) and white mustard (Brassica alba (L.) Rabenh.) have no obvious carbon storage structures and were assumed to have a lower sink strength relative to the above cultivars. Plants were harvested at three stages of development and total plant weight, leaf area ratio, and allocation to leaf, root, and stem determined. As young seedlings, all cultivars responded positively to elevated CO2. The long-term growth response of different cultivars to CO2 was independent of sink location, but was dependent on sink size. Cultivars with no obvious carbon storage structures showed no significant growth enhancement by elevated CO2 by the end of the experiment. However, neither leaf area ratio nor biomass allocation pattern were reliable predictors of response to CO2 suggesting that assessing differences in source to sink ratio is not necessarily straightforward.

KEYWORDS: ENRICHMENT, PHOTOSYNTHESIS, PINE, PLANTS, TEMPERATURE

1953

Reekie, J.Y.C., P.R. Hicklenton, and E.G. Reekie. 1994. Effects of elevated co2 on time of flowering in 4 short-day and 4 long-day species. *Canadian Journal of Botany-Revue Canadienne De Botanique 72(4):533-538.*

This study was undertaken to determine if the effect of elevated CO2 on flowering phenology is a function of the photoperiodic response of the species involved. Four long-day plants, Achillea millefolium, Callistephus chinensis, Campanula isophylla, and Trachelium caeruleum, and four short-day plants, Dendranthema grandiflora, Kalanchoe blossfeldiana, Pharbitis nil, and Xanthium pensylvanicum, were grown under inductive photoperiods (9 h for short day and 17 h for long day) at either 350 or 1000 mu L/L CO2. Time of visible flower bud formation, flower opening, and final plant biomass were assessed. Elevated CO2 advanced flower opening in all four long-day species and delayed flowering in all four short-day species. In the long-day species, the effect of CO2 was primarily on bud initiation; all four species formed buds earlier at high CO,. Bud development, the difference in time between flower opening and bud initiation, was advanced in only one long-day species, Callistephus chinensis. Mixed results were obtained for the short-day species. Elevated CO, exerted no effects on bud initiation but delayed bud development in Dendranthema and Kalanchoe. In Xanthium, bud initiation rather than bud development was delayed. Data on bud initiation and development were not obtained for Pharbitis. The negative effect of CO, upon phenology in the short-day species was not associated with negative effects on growth. Elevated CO2 increased plant size in both long-day and short-day species.

KEYWORDS: CARBON DIOXIDE, ENRICHMENT, GROWTH, PHARBITIS

1954

Reekie, J.Y.C., P.R. Hicklenton, and E.G. Reekie. 1997. The interactive effects of carbon dioxide enrichment and daylength on growth and development in Petunia hybrida. *Annals of Botany 80(1):57-64.*

Plants were grown at either 350 or 1000 mu l l(-1) CO2 and in one of three photoperiod treatments: continuous short days (SD), continuous long days (LD), or short switched to long days at day 41 (SD-LD). All plants received 9 h of light at 450 mu mol m(-2) s(-1) and LD plants received an additional 4 h of light at 8 mu mol m(-2) s(-1). Growth of SD plants responded more positively to elevated CO2 than did LD plants, due largely to differences in the effect of CO2 on unit leaf rate. High CO2 increased height and decreased branching under SD conditions, but had no effect under LD conditions. Elevated CO2 also increased the number of buds and open flowers, the effect for flower number being greater in short than in long days. The specific leaf area of plants grown at 1000 mu l l(-1) CO2 was reduced regardless of daylength. High CO2 also decreased leaf and increased reproductive allocation, the magnitude of these effects being greater under SD conditions. Bud formation and flower opening was advanced under high CO2 conditions in SD plants but bud formation was delayed and there was no effect on flower opening under LD conditions. The effects of CO2 on plants switched from SD to LD conditions were largely intermediate between the two continuous treatments, but for some parameters, more closely resembled one or the other. The results illustrate that daylength is an important factor controlling response of plants to elevated CO2. (C) 1997 Annals of Botany Company.

KEYWORDS: AMBIENT, C-3, ELEVATED CO2, INCREASING CO2 CONCENTRATION, IRRADIANCE, PHARBITIS, PHOTOSYNTHESIS, PLANT GROWTH, RESPONSES, TEMPERATURE

1955

Reeves, D.W., H.H. Rogers, S.A. Prior, C.W. Wood, and G.B. Runion. 1994. Elevated atmospheric carbon-dioxide effects on sorghum and soybean nutrient status. *Journal of Plant Nutrition 17(11):1939-1954.*

Increasing atmospheric carbon dioxide (CO2) concentration could have significant implications on technologies for managing plant nutrition to sustain crop productivity in the future. Soybean (Glycine max [L.] Merr.) (C3 species) and grain sorghum (Sorghum bicolor [L.] Moench) (C4 species) were grown in a replicated split-plot design using open-top field chambers under ambient (357 mu mol/mol) and elevated (705 mu mol/mol) atmospheric CO2. At anthesis, leaf disks were taken from upper mature leaves of soybean and from the third leaf below the head of sorghum for analysis of plant nutrients. Leaf greenness was measured with a Minolta SPAD-502 chlorophyll meter. Concentrations of chlorophylls a and b and specific leaf weight were also measured. Above-ground dry matter and seed yield were determined at maturiry. Seed yield of sorghum increased 17.5% and soybean seed yield increased 34.7% with elevated CO2. There were no differences in extractable chlorophyll concentration or chlorophyll meter readings due to CO2 treatment, but meter readings were reduced 6% when sorghum was grown in chambers as compared in the open. Leaf nitrogen (N)

concentration of soybean decreased from 54.5 to 39.1 g/kg at the higher CO2 concentration. Neither the chambers nor CO2 had an effect on concentrations of other plant nutrients in either species. Further work under field conditions is needed to determine if current critical values for tissue N in crops, especially C3 crops, should be adjusted for future increases in atmospheric CO2 concentration.

KEYWORDS: CHLOROPHYLL METER, CO2- ENRICHMENT, EXCHANGE-RATES, FIELD, GROWTH, MAIZE, MINERAL NUTRITION, NITROGEN STATUS, RESPONSES, WHEAT

1956

Refouvelet, E., and F. Daguin. 1999. Polymorphic glutamate dehydrogenase in lilac vitroplants as revealed by combined preparative IEF and native PAGE: Effect of ammonium deprivation, darkness and atmospheric CO2 enrichment upon isomerization. *Physiologia Plantarum 105(2):199-206.*

The activity and polymorphism of glutamate dehydrogenase (GDH) were studied in basal callus of Lilac (Syringa eulgaris L.) vitroplants. Native PAGE alone revealed seven bands staggered at regular intervals. Preparative liquid-vein IEF allowed the separation of six to ten GDH fractions with charges ranging between 5.18 and 7.08. Analysis of these GDH fractions in native PAGE indicated that up to seven GDH bands can be detected for each fraction. This suggests the existence of seven isoforms of the enzyme with subunits presenting different isoelectric points. Dark- and ammonium-controlled forms were found to be the more acidic and faster migrating ones in native PAGE. The results support for the first time that atmospheric CO2 enrichment increases GDH activity dramatically and modifies isomerization of the enzyme.

KEYWORDS: ARABIDOPSIS-THALIANA, HIGHER-PLANTS, LEAF, MITOCHONDRIA, NITROGEN ASSIMILATION, SYNTHETASE, TISSUES

1957

Reich, P.B. 1995. Phenology of tropical forests - patterns, causes, and consequences. *Canadian Journal of Botany-Revue Canadienne De Botanique 73(2):164-174.*

Leaf phenology of tropical forests is distinct from other biomes. Unlike the marked temperature-related periodicity of temperate forests, development tends to be continuous in aseasonal lowland tropical rain forests and becomes more episodic in response to increasing annual drought in tropical dry forests. Hence, in tropical rain forests, foliar development (production, senescence, and longevity) is largely under internal rather than environmental control. In contrast, tropical forests with marked annual dry seasons display associated seasonality of leaf production and shedding. This developmental seasonality can be explained by overlaying the influence of seasonality on trees' internally regulated development and appears to be controlled by acclimative physiological processes and not by sensitivity to photo-, thermo-periodic, or direct environmental cues. Consequences of tropical phenology stem from both the variety of leaf and species ecophysiological types common to a given moisture regime and their relative synchrony of development, and include the following: larger diversity of ecophysiological species types in rain than dry forests; differential rates of herbivory in dry than wet seasons and for synchronous versus asynchronous leaf flushes; ecosystems with greater canopy foliar mass per hectare in rain than dry forests; and several leaf adaptations perhaps unique to tropical forests, such as delayed greening and seasonal leaf phenotypes. Tropical forests may vary in sensitivity to predicted climate change. Phenology of rain forests should change little unless water balance changes markedly, and developmental events in rain forests may be relatively insensitive to moderate changes in CO2 or temperature. Phenology of dry forests could be more sensitive, and in opposite directions, to elevated CO2 and temperatures. Elevated CO2 might delay the onset of leaf shedding and stimulate longer life span if stand level transpiration is reduced, whereas higher temperatures could lead to more rapid water depletion, longer leafless periods, and more strongly synchronized phenology.

KEYWORDS: COSTA-RICA, DECIDUOUS FOREST, DRY FOREST, HERBIVORY, LEAF LIFE-SPAN, LONGEVITY, LOWLANDS, SEASONAL DROUGHT, TREES, UNDERSTORY COMMUNITY

1958

Reich, P.B., J. Oleksyn, and M.G. Tjoelker. 1996. Needle respiration and nitrogen concentration in Scots Pine populations from a broad latitudinal range: A common garden test with field-grown trees. *Functional Ecology 10(6):768-776.*

1. Models of tree function and forest ecosystem carbon budgets often assume that potential global changes in temperature and/or other factors may alter tissue nitrogen (N) and dark respiration rates (R(d)). However, little is known of patterns of co-variation in tissue N and R(d) among intraspecific populations originating along climatic gradients, and of whether an N-based model of R(d) can link these two variables. To address these issues, we studied N and R(d) in fully expanded needles of 10-year-old trees of 14 Scots Pine (Pinus sylvestris) populations of wide-ranging origin (43 degrees to 60 degrees N), grown under common garden conditions. 2. For 11 lowland populations (elevation <200 m) from the contiguous part of the species range (48 degrees to 60 degrees N) grown at a field site in Kornik, western Poland (52 degrees N), there were greater needle %N in populations from increasing latitude of origin or decreasing mean annual temperature (r greater than or equal to 0.93, P<0.01). Similar %N and latitude of origin correlations were observed in another year at this site and in retrospective analyses of published data for different sets of Scots Pine populations grown in common gardens at 48 degrees, 52 degrees C and 62 degrees N latitudes. Needle R(d) rates of the 11 lowland populations growing at Kornik and measured at a common temperature (20 degrees C) were greater, by as much as 50%, for more northerly than southerly populations. Mean R(d) rates were positively correlated to latitude of origin and to mean annual temperature (P<0.05, r=0.7 to 0.8). R(d) and needle %N were positively correlated (P<0.01, r=0.75), with one relationship fitting all data. Across the entire range from 1.15 to 1.55 needle %N, R(d) increased from 4.5 to 6.9 nmol g(- 1) s(-1). 3. Mean needle %N and R(d) values for two montane southern populations (43 degrees and 44 degrees N, elevation greater than or equal to 885 m) growing in the same common garden at Kornik were consistent with the relationships between mean annual temperature, needle %N and R(d) observed for the more northerly populations but did not fit the latitudinal patterns. This suggests that temperature and/or associated climate variables are likely the driving force for observed genetic variation in Scots Pine needle %N and R(d) across latitudinal and altitudinal gradients. 4. Results of these common garden studies support the idea of a general relationship between needle dark respiration and N concentration, and indicate that there is intraspecific genetic variation in physiology that is selected by climate that persists in a common environment, resulting in higher needle %N and respiration in plants originating from colder habitats. Such patterns need to be better understood and quantified, and merit consideration in modelling of current and potential global change effects on plant function and global carbon cycles.

KEYWORDS: AIR-POLLUTION, CLIMATE CHANGE, CO2 EXCHANGE, DARK RESPIRATION, GRADIENTS, MAINTENANCE RESPIRATION, PHOTOSYNTHESIS, PLANTS, SYLVESTRIS L, TEMPERATURE

1959

Reichenauer, T., H.R. BolharNordenkampf, U. Ehrlich, G. Soja,

W.F. Postl, and F. Halbwachs. 1997. The influence of ambient and elevated ozone concentrations on photosynthesis in Populus nigra. *Plant, Cell and Environment 20(8):1061-1069.*

Light-saturated net leaf photosynthesis (A(sat)), CO2 response curves (A/C-i), current photochemical capacity (F-v/F-m) and pigment contents were measured in leaves of Populus nigra (Clone T107) which had been exposed to ozone stress in open-top chambers for the entire growth period. Surprisingly, not only elevated (ao(+), i.e. ambient air + 50 mm(3) m(-3) ozone) but also ambient (aa) ozone concentrations led to a reduction in A(sat) in comparison with leaves exposed to air containing almost no ozone (cf(-), i.e. charcoal filtered ambient air). The very small change in leaf conductance (g(l)) indicated that the decrease in A(sat) was not due to stomatal limitation. This finding was supported by the fact that, a decrease in carboxylation efficiency (CE) correlated with a loss in A(sat). In comparison to cf-leaves, aa leaves showed no change in current photochemical capacity (F-v/F-m) throughout the whole experiment. However, a marked decline in F-v/F-m in ao(+) leaves was observed at a time when A(sat) and CE were already decreased by about 45% and 60% respectively. As the chlorophyll b content of leaves is known to correlate with the amount of LHC and PSII centres, it was used to normalize fluorescence parameters in relation to PSII centres present. The normalized values for F-m and F-O increased with the dosage of ozone in ao(+) leaves but not in aa leaves, indicating a change of the pigment content of PSII in the former, but not in the latter. These data led to the conclusion that ozone interacts primarily with components of the Calvin cycle, which results in a decrease in A(sat) with subsequent feedback on the current photochemical capacity of PSII centres.

KEYWORDS: AIR- POLLUTANTS, BISPHOSPHATE CARBOXYLASE OXYGENASE, CHLOROPHYLL FLUORESCENCE, DELTA C 13, EXPOSURE, LEAVES, NET PHOTOSYNTHESIS, PLANTS, STOMATAL CONDUCTANCE, STRESS

1960

Reicosky, D.C., D.W. Reeves, S.A. Prior, G.B. Runion, H.H. Rogers, and R.L. Raper. 1999. Effects of residue management and controlled traffic on carbon dioxide and water loss. *Soil & Tillage Research 52(3-4):153-165.*

Management of crop residues and soil organic matter is of primary importance in maintaining soil fertility and productivity and in minimizing agricultural impact on the environment. Our objective was to determine the effects of traffic and tillage on short-term carbon dioxide (CO2) and water (H2O) fluxes from a representative soil in the southeastern Coastal Plain (USA). The study was conducted on a Norfolk loamy sand (FAO classification, Luxic Ferralsols; USDA classification, fine-loamy siliceous, thermic Typic Kandiudults) cropped to a corn (Zea mays L.)- soybean (Glycine maw (L.) Merr) rotation with a crimson clover (Trifolium incarnatum L.) winter cover crop for eight years. Experimental variables were with and without traffic under conventional tillage (CT) (disk harrow twice, chisel plow, field cultivator) and no tillage (NT) arranged in a split-plot design with four replicates. A wide-frame tractive vehicle enabled tillage without wheel traffic. Short-term CO2 and H2O fluxes were measured with a large portable chamber. Gas exchange measurements were made on both CT and NT at various times associated with tillage and irrigation events. Tillage-induced COP and H2O fluxes were larger than corresponding fluxes from untilled soil. Irrigation caused the CO2 fluxes to increase rapidly from both tillage systems, suggesting that soil gas fluxes were initially limited by lack of water. Tillage-induced CO2 and H2O fluxes were consistently higher than under NT. Cumulative CO2 flux from CT at the end of 80 h was nearly three times larger than from NT while the corresponding H2O loss was 1.6 times larger. Traffic had no significant effects on the magnitude of CO:! fluxes, possibly reflecting this soil's natural tendency to reconsolidate. The immediate impact of intensive surface tillage of sandy soils on gaseous carbon loss was larger than traffic effects and suggests a need to develop new management practices for enhanced soil carbon and water management for these sensitive soils.

KEYWORDS: BIOMASS, CORN, NITROGEN, SOIL RESPIRATION, TILLAGE SYSTEM

1961

Reid, C.D., and E.L. Fiscus. 1998. Effects of elevated [CO2] and/or ozone on limitations to CO2 assimilation in soybean (Glycine max). *Journal of Experimental Botany 49(322):885-895.*

Soybean (Glycine max) was grown in open-top field chambers at ambient (360 mu mol mol(-1)) or doubled [CO2] either in charcoal-filtered air (20 nmol mol(-1) [O-3]) or in non- filtered air supplemented to 1.5 x ambient [O-3] (70 nmol mol(- 1)) to determine the major limitations to assimilation under conditions of elevated [CO2] and/or [O-3]. Through plant ontogeny, assimilation versus intercellular CO2 concentration (A/Ci) responses were measured to assess the limitations to assimilation imposed by the capacity for Rubisco carboxylation, RuBP regeneration, and stomatal diffusion. In the vegetative stages, no significant treatment effects of elevated [CO2] and/or [O-3] were observed on Rubisco carboxylation efficiency (CE), light and CO2-saturated assimilation capacity (A(max)), and chlorophyll content (Chl). However, for plants grown in elevated [CO2], the assimilation rate at growth [CO2] (A) was 60% higher than at ambient [CO2] up to the seed maturation stage, and the potential rate of assimilation by Rubisco capacity (A(p)) was increased. Also in elevated [CO2]: A was 51% of A(p); the relative stomatal limitation (%Stomata) was 5%; and the relative RuBP regeneration limitation (%RuBP) was 44%. In ambient [CO2], O-3 gradually decreased A per unit leaf area, but had little effect on A, and the relative limitations to assimilation where A remained 51% of A(p), %Stomata was 27%, and %RuBP was 22%. During reproduction, CE declined for plants grown in elevated [CO2] and/or [O-3]; A(p) was unaffected by elevated [CO2], but was reduced by [O-3] at ambient [CO2]; A increased to 72% of A(p) in elevated [CO2] and/or [O-3]- fumigated air; the %Stomata increased; and the %RuBP decreased, to become non significant in elevated [CO2] from the beginning of seed growth on, and in O-3-fumigated air at ambient [CO2] at the seed maturation stage. The decrease in %RuBP occurred concomitantly with an increase in A(max) and Chl. Significant [CO2] x [O-3] interactions support the lack of an O-3 effect on assimilation and its limitations at elevated [CO2] during seed maturation. These data suggest that elevated [CO2] alleviated some of the effects of O-3 on photosynthesis.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, GAS-EXCHANGE, LEAF PROTEINS, NET PHOTOSYNTHESIS, OPEN-TOP CHAMBERS, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, SPRING WHEAT, STOMATAL CONDUCTANCE, TRITICUM-AESTIVUM L

1962

Reid, C.D., E.L. Fiscus, and K.O. Burkey. 1998. Combined effects of chronic ozone and elevated CO2 on Rubisco activity and leaf components in soybean (Glycine max). *Journal of Experimental Botany 49(329):1999-2011.*

Content and activity of Rubisco and concentrations of leaf nitrogen, chlorophyll and total non-structural carbohydrates (TNC) were determined at regular intervals during the 1993 and 1994 growing seasons to understand the effects and interactions of [O-3] and elevated [CO2] on biochemical limitations to photosynthesis during ontogeny. Soybean (Glycine max var. Essex) was grown in open-top field chambers in either charcoal- filtered air (CF, 20 nmol mol(-1)) or non-

filtered air supplemented with 1.5 x ambient [O-3] (c. 80 nmol mol(-1)) at ambient (AA, 360 mu mol mol(-1)) or elevated [CO2] (700 pmol mol(-1)). Sampling period significantly affected all the variables examined. Changes included a decrease in the activity and content of Rubisco during seed maturation, and increased nitrogen (N), leaf mass per unit area (LMA) and total non- structural carbohydrates (TNC, including starch and sucrose) through the reproductive phases. Ontogenetic changes were most rapid in O-3-treated plants. At ambient [CO2], O-3 decreased initial activity (14-64% per unit leaf area and 14-29% per unit Rubisco) and content of Rubisco (9-53%), and N content per unit leaf area. Ozone decreased LMA by 17-28% of plants in CF-AA at the end of the growing season because of a 24-41% decrease in starch and a 59-80% decrease in sucrose. In general, elevated [CO2] in CF or O-3-fumigated air, reduced the initial activity of Rubisco and activation state while having little effect on Rubisco content, N and chlorophyll content, per unit leaf area. Elevated CO2 decreased Rubisco activity by 14-34% per unit leaf area and 15-25% per unit Rubisco content of plants in grown CF- AA, and increased LMA by 27-74% of the leaf mass per unit area in CF-AA because of a 23-148% increase in starch. However, the data suggest that, at elevated [CO2], increases in starch and sucrose are not directly responsible for the deactivation of Rubisco. Also, there was little evidence of an adjustment of Rubisco activity in response to starch and sucrose metabolism. Significant interactions between elevated [CO2] and [O-3] on all variables examined generally resulted in alleviation or amelioration of the O-3 effects at elevated CO2. These data provide further support to the idea that elevated atmospheric CO2 will reduce or prevent damage from pollutant O-3.

KEYWORDS: ACCLIMATION, CARBON DIOXIDE, LEAVES, NET PHOTOSYNTHESIS, O-3, PHOTOSYNTHETIC APPARATUS, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, TOMATO PLANTS, TRITICUM-AESTIVUM L, WHEAT

1963

Reid, C.D., E.L. Fiscus, and K.O. Burkey. 1999. Effects of chronic ozone and elevated atmospheric CO2 concentrations on ribulose-1,5-bisphosphate in soybean (Glycine max). *Physiologia Plantarum 106(4):378-385.*

Ribulose-1,5-bisphosphate (RuBP) pool size was determined at regular intervals during the growing season to understand the effects of tropospheric ozone concentrations, elevated atmospheric carbon dioxide concentrations and their interactions on the photosynthetic limitation by RuBP regeneration. Soybean (Glycine max [L.] Merr, cv, Essex) was grown from seed to maturity in open-top field chambers in charcoal-filtered air (CF) either without (22 nmol O-3 mol(-1)) or with added O-3 (83 nmol mol(-1)) at ambient (AA, 369 mu mol CO2 mol(-1)) or elevated CO, (710 mu mol mol(-1)). The RuBP pool size generally declined with plant age in all treatments when expressed on a unit leaf area and in all treatments but CF-AA when expressed per unit ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco; EC 4,1,1,39) binding site, Although O-3 in ambient CO2 generally reduced the RuBP pool per unit leaf area, it did not change the RuBP pool per unit Rubisco binding site, Elevated CO2, in CF or O-3-fumigated air, generally had no significant effect on RuBP pool size, thus mitigating the negative O-3 effect. The RuBP pools were below 2 mol mol(-1) binding site in all treatments for most of the season, indicating limiting RuBP regeneration capacity. These low RuBP pools resulted in increased RuBP regeneration Fia faster RUBP turnover, but only in CF air and during vegetative and flowering stages at elevated CO2. Also, the low RuBP pool sizes did not always reflect RuBP consumption rates or the RuBP regeneration limitation relative to potential carboxylation (%RuBP). Rather, %RuBP increased linearly with decrease in the RuBP pool turnover lime. These data suggest that amelioration of damage from O-3 by elevated atmospheric CO2 to the RuBP regeneration may be in response to changes in the Rubisco carboxylation.

KEYWORDS: CARBOXYLASE OXYGENASE ACTIVITY, LEAVES, O-3, PHASEOLUS-VULGARIS L, PHOTOSYNTHESIS, PLANTS, POOL SIZES, RIBULOSE 1;5-BISPHOSPHATE, SPRING WHEAT, STATE GAS-EXCHANGE

1964

Reid, C.D., and B.R. Strain. 1994. Effects of co(2) enrichment on whole-plant carbon budget of seedlings of fagus-grandifolia and acer-saccharum in low irradiance. *Oecologia 98(1):31-39.*

Carbon exchange rates (CER) and whole-plant carbon balances of beech (Fagus grandifolia) and sugar maple (Acer saccharum) were compared for seedlings grown under low irradiance to determine the effects of atmospheric CO2 enrichment on shade-tolerant seedlings of co-dominant species. Under contemporary atmospheric CO2, photosynthetic rate per unit mass of beech was lower than for sugar maple, and atmospheric CO2 enrichment enhanced photosynthesis for beech only. Aboveground respiration per unit mass decreased with CO2 enrichment for both species while root respiration per unit mass decreased for sugar maple only. Under contemporary atmospheric CO2, beech had lower C uptake per plant than sugar maple, while C losses per plant to nocturnal aboveground and root respiration were similar for both species. Under elevated CO2, C uptake per plant was similar for both species, indicating a significant relative increase in whole-seedling CER with CO2 enrich ment for beech but not for sugar maple. Total C loss per plant to aboveground respiration was decreased for beech only because increase in sugar maple leaf mass counterbalanced a reduction in respiration rates. Carbon loss to root respiration per plant was not changed by CO2 enrichment for either species. However, changes in maintenance respiration cost and nitrogen level suggest changes in tissue composition with elevated CO2. Beech had a greater net daily C gain with CO2 enrichment than did sugar maple in contrast to a lower one under contemporary CO2. Elevated CO2 preferentially enhances the net C balance of beech by increasing photosynthesis and reducing respiration cost. In all cases, the greatest C lost was by roots, indicating the importance of belowground biomass in net C gain. Relative growth rate estimated from biomass accumulation was not affected by CO2 enrichment for either species possibly because of slow growth under low light. This study indicates the importance of direct effects of CO2 enrichment when predicting potential change in species distribution with global climate change.

KEYWORDS: ATMOSPHERIC CO2 CONCENTRATION, CLIMATE CHANGE, ELEVATED CO2, GAS-EXCHANGE, GROWTH, LIQUIDAMBAR- STYRACIFLUA, PHOTOSYNTHESIS, PINUS-TAEDA SEEDLINGS, RESPIRATION, WATER-STRESS

1965

Reid, C.D., D.T. Tissue, E.L. Fiscus, and B.R. Strain. 1997. Comparison of spectrophotometric and radioisotopic methods for the assay of Rubisco in ozone-treated plants. *Physiologia Plantarum 101(2):398-404.*

Radioisotopic and spectrophotometric assays for ribulose-1,5-bisphosphate carboxy lase/oxygenase (Rubisco) initial and final activities and Rubisco content were compared in plants chronically exposed to ozone (O-3) in a greenhouse and the field. In a greenhouse experiment, Glycine max was treated in exposure chambers with either charcoal-filtered air (CF air) or 100 nl O-3 l(-1) for 6 h daily during vegetative growth. Samples were collected after 7 days of exposure. In a field experiment, G. max was treated in open-top chambers with either CF air or nonfiltered air with O-3 added at 1.5 times ambient O-3 for 12 h daily. Average daily O-3 concentrations were 21 and 92 nl l(-1) in the CF and O-3 treatments, respectively samples were collected during vegetative and reproductive growth, Both assays generally yielded comparable Rubisco initial and final activities for greenhouse-grown

plants regardless of the O-3 treatment. However for field-grown plants, Rubisco initial and final activities averaged 15 and 23% lower when assayed by the spectrophotometric rather than the radioisotopic method. For Rubisco content estimated by the spectrophotometric method, lower r(2) values for the regression of Rubisco activity vs concentration of carboxyarabinitol-1,5- bisphosphate were observed in O3- than in CF-treated plants. Both assays yielded comparable Rubisco contents in the greenhouse and in the field although the variation was larger with the spectrophotometric method in field-grown plants. Growth conditions, field vs greenhouse, were more critical to the spectrophotometric assay performance than the O-3 treatments for measurement of Rubisco activity and content.

KEYWORDS: 1,5-BISPHOSPHATE, ACTIVATION, ELEVATED CO2, LIGHT-DEPENDENT REGULATION, NET PHOTOSYNTHESIS, PHASEOLUS-VULGARIS L, POOL SIZES, RIBULOSE BISPHOSPHATE CARBOXYLASE, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE, RUBP CARBOXYLASE

1966

Reinert, R.A., G. Eason, and J. Barton. 1997. Growth and fruiting of tomato as influenced by elevated carbon dioxide and ozone. *New Phytologist 137(3):411-420.*

'Tiny Tim' tomato plants were exposed to five CO2 treatments (375 (ambient), 450, 525, 600 or 675 mu mol mol(-1)) in combination with O-3 (O or 80 nmol mol(-1)). Biomass was evaluated following 3, 5, 7 and 13 wk exposure. Biomass following 13 wk exposure also included weekly harvests of mature tomato fruit beginning week 8. Carbon dioxide enrichment significantly enhanced total vegetative plant d. wt at each harvest, as well as cumulative yield of mature fruit, whereas O-3 significantly suppressed total Vegetative plant d. wt at each harvest and reduced total cumulative fruit yield. The magnitude of these changes varied with the development of tomato from early growth to mature fruit yield. Carbon dioxide enrichment reduced the detrimental effects of O-3 on total vegetative plant d. wt of tomato following 3, 5, 7 and 13 wk exposure. Final mature fruit yield was 24% higher under enriched CO2 treatments than in ambient CO2. Ozone suppressed final yield by 31% following exposure to 80 nmol mol(-1) O-3 when compared with exposure to charcoal-filtered (CF) air. The impacts of both CO2 and O-3 on yield were, however, dependent upon the presence or absence of the other gas. In the absence of O-3, yields were very similar for the ambient and elevated CO2 treatments, but in the presence of O-3, yields under ambient CO2 were greatly suppressed whereas yields under elevated CO2 were similar to those in the absence of O-3. Thus, enriched CO2 ameliorated most of the suppressive effect of O-3 on yield of mature fruit.

KEYWORDS: ATMOSPHERIC CO2, CO2- ENRICHMENT, ENVIRONMENT, EXCHANGE, PHOTOSYNTHETIC ACCLIMATION, RADISH, RESPONSES, TEMPERATURE, VEGETATION, YIELD

1967

Reinert, R.A., and M.C. Ho. 1995. Vegetative growth of soybean as affected by elevated carbon- dioxide and ozone. *Environmental Pollution 89(1):89-96.*

The effects of elevated carbon dioxide (CO2) and ozone (O-3) on soybean (Glycine max (L.) Merr. cv. Centennial) growth and biomass partitioning were evaluated under greenhouse conditions. Soybeans were exposed to CO2 concentrations at 350 (ambient), 450, 550, and 650 mu l liter(-1) (ppm) for 24 h day(-1) for 5 weeks. Ozone treatments of 0 and 120 nl liter(-1) (ppb) for 6 h day(-1) for 5 days week-1 for 5 weeks were added in combination with the CO2 treatments. Plant dry weight and biomass partitioning were assessed each week. Dry weight of leaf, stem, and root, as well as the total plant dry weight increased with exposure to increasing levels of CO2. Dry weight of leaf, root and total plant were suppressed significantly by the O-3 treatment. Stem dry weight was not affected by O-3. Suppression of root dry weight due to O-3 at each weekly harvest was significantly dependent on the CO2 concentration. Root growth was enhanced by CO2 at 650 mu l liter(-1) compared with ambient CO2 (350 mu l liter(-1)) at 5 weeks of age. At ambient CO2 in the presence of O3 the roots were only about 63% of the weight of the root grown in the absence of O-3. At 550 and 650 mu l liter(-1) CO2 the biomass of soybean roots in the presence of 120 nl liter(-1) O-3 was 88.2 and 88.4% of the control, respectively. Thus, CO2 limited the amount of root growth suppression caused by O-3. The partitioning of leaf, stems and root dry weight in relation to total plant dry weight remained relatively constant across each CO2 concentration. Thus, CO2 did not affect biomass partitioning among leaves, stems and roots of soybean.

KEYWORDS: CO2- ENRICHMENT, COMBINATION, EXPOSURE, FIELD, NITROGEN, PHOTOSYNTHESIS, RESPONSES, SEED YIELD, SOIL-WATER DEFICIT, TEMPERATURE

1968

Reining, E. 1994. Acclimation of C-3 photosynthesis to elevated co2 - hypotheses and experimental-evidence. *Photosynthetica 30(4):519-525.*

Acclimation of the photosynthesis of C-3 plants to elevated atmospheric CO2 concentrations is frequently observed. Some hypotheses frequently proposed to explain this phenomenon are: (1) stomatal closure; (2) inhibition of photosynthesis by starch accumulation, and (3) reduced activity or concentration of ribulose-1,5-bisphosphate carboxylase/oxygenase. These hypotheses are compared with experimental evidence from the literature.

KEYWORDS: ATMOSPHERIC CARBON-DIOXIDE, CARBOHYDRATE, ENRICHMENT, GAS-EXCHANGE, GROWTH, LONG-TERM EXPOSURE, PHASEOLUS-VULGARIS L, PLANTS, RIBULOSE BISPHOSPHATE CARBOXYLASE, STARCH

1969

Reining, F. 1995. The effect of elevated co2 concentrations on the competition between lamium-galeobdolon and stellaria-holostea. *Photosynthetica 31(4):501-508.*

The effect of enhanced air CO2 concentrations (c(520) and c(650) = 520 and 650 cm(3) m(-3)) on the growth of Lamium galeobdolon and Stellaria holostea and on the competition between the two species was examined. After five months growth under CO2 enrichment the dry masses of both species increased when the plants were grown in monoculture, but the increase in biomass was much more pronounced in Stellaria. When the plants were grown together in competition, the measured shoot masses of Stellaria were again higher under c(520) and c(650) than at ambient CO2 concentration (c(390) = 390 cm(3) m(-3)), while the shoot masses of lamium strongly decreased at c(650) The effect of CO2 enrichment on the two plant species in monoculture differed significantly from that observed in mixed cultures. In terms of plant relative yield. Stellaria benefitted slightly but insignificantly from competition, while Lamium was significantly suppressed under c(650). Total community production of the mixed culture was optimum at c(520), while that of the monocultures was highest at c(650) At c(390) and c(520), growth of Stellaria depended strongly on irradiance in all types of culture. At c(650) no such dependence could be demonstrated.

KEYWORDS: ANNUALS, ASSEMBLAGE, CARBON DIOXIDE, CROP RESPONSES, ENRICHMENT, GROWTH, OLD- FIELD PERENNIALS, PLANTS

1970

Reitz, S.R., D.N. Karowe, M.M. Diawara, and J.T. Trumble. 1997. Effects of elevated atmospheric carbon dioxide on the growth and linear furanocoumarin content of celery. *Journal of Agricultural and Food Chemistry 45(9):3642-3646.*

The effects of elevated atmospheric carbon dioxide on the growth and development of celery (Apium graveolens) were examined to determine if anticipated global increases in CO2 will affect the nutritional quality and secondary chemistry of celery. The size (fresh and dry mass), nitrogen and carbon composition, and concentrations of linear furanocoumarins of celery grown under ambient (363 mu L L-1) and elevated (718 mu L L-1) carbon dioxide were analyzed. Growth under elevated CO2 resulted in larger petioles, reduced nitrogen content, and higher C:N ratios in both leaves and petioles. However, CO2 treatment did not affect plant water content or carbon content. Moreover, in contrast to the carbon-nutrient balance hypothesis, the increased C:N ratios of plants grown under elevated CO2 were not associated with increased concentrations of potentially harmful linear furanocoumarins. Levels of linear furanocoumarins in the petioles of plants from each treatment did not exceed concentrations reported to cause acute or chronic contact dermatitis.

KEYWORDS: ALLELOCHEMICALS, ALLOCATION PATTERNS, CO2 ENVIRONMENTS, ELEMENTAL ORGANIC-ANALYSIS, ENRICHMENT, INTEGRATED PEST-MANAGEMENT, NUTRIENT BALANCE, PERFORMANCE, RESISTANCE, RESPONSES

1971

Rennenberg, H., and A. Gessler. 1999. Consequences of N deposition to forest ecosystems - Recent results and future research needs. *Water, Air, and Soil Pollution 116(1-2):47-64.*

Wet and dry deposition of atmospheric nitrogen (N) compounds into forest ecosystems and their effect on physical, chemical and microbial processes in the soil has attracted considerable attention for many years. Still the consequences of atmospheric N deposition on N metabolism of trees and its interaction with soil microbial processes has only recently been studied. Atmospheric N deposited to the leaves is thought to enter the general N metabolism of the leaves, but the processes involved, the interaction with different metabolic pathways, and the connection between injury by atmospheric N and its metabolic conversion are largely unknown. Laboratory and field experiments have shown that N of atmospheric NO2 and NH3, deposited to the leaves of trees, is subject to long-distance transport in the phloem to the roots. This allocation can result in considerable decline of N uptake by the roots. Apparently, the flux of N from the soil into the roots can be down-regulated to an extent that equals N influx into the leaves. This down-regulation is not mediated by generally enhanced amino-N contents, but by elevated levels of particular amino acids. Field experiments confirm these results from laboratory studies: Nitrate (NO3) uptake by the roots of trees at a field sites exposed to high loads of atmospheric N is negligible, provided concentrations of Gln in the roots are high. At the ecosystem level, consequences of reduced N uptake by the roots of trees exposed to high loads of atmospheric N are (1) an increased availability of N for soil microbial processes, (2) enhanced emission of gaseous N-oxides from the soil, and (3) elevated leaching of NO3 into the ground water. How recent forest management practices aimed at transforming uniform monocultures to more structured species-rich forests will interact with these processes remains to be seen. Possible implications of these forest management practices on N metabolism in trees and N conversion in the soil are discussed particularly in relation to atmospheric N deposition.

KEYWORDS: AMINO-ACIDS, ATMOSPHERIC AMMONIA, DYNAMIC CHAMBER EXPERIMENTS, ELEVATED CO2, GLUTAMINE-SYNTHETASE ISOFORMS, HORDEUM VULGARE L, L KARST, NITRATE REDUCTASE, NITROGEN-DIOXIDE, SPRUCE PICEA-ABIES

1972

Repo, T., H. Hanninen, and S. Kellomaki. 1996. The effects of long-term elevation of air temperature and CO2 on the frost hardiness of Scots pine. *Plant, Cell and Environment 19(2):209-216.*

The frost hardiness of 20 to 25-year-old Scots pine (Pinus sylvestris L.) saplings was followed for 2 years in an experiment that attempted to simulate the predicted climatic conditions of the future, i,e, increased atmospheric CO2 concentration and/or elevated air temperature, Frost hardiness was determined by an electrolyte leakage method and visual damage scoring on needles, Elevated temperatures caused needles to harden later and deharden earlier than the controls, In the first year, elevated CO2 enhanced hardening at elevated temperatures, but this effect disappeared the next year, Dehardening was hastened by elevating CO2 in both springs, The frost hardiness was high (<-40 degrees C), even at elevated temperatures, in midwinter, at which time the electrolyte leakage method underestimated the frost hardiness compared with the visual scoring, In addition to the significant differences between treatments, there was also significant variation between trees in frost hardiness within treatments, These results suggest that the risks of frost damage are marked in the predicted climatic conditions in Finland, and, more specifically, they depend on how the occurrence of the frost episodes changes with respect to climatic warming during the annual cycle, especially in the autumn and spring, We also conclude that the conditions in midwinter are not critical for frost injury to trees in the future.

KEYWORDS: BUDBURST, DAMAGE, SEASONAL-CHANGES, SEEDLINGS, TREES

1973

Retamales, J., T. Cooper, J. Streif, and J.C. Kania. 1992. Preventing cold-storage disorders in nectarines. *Journal of Horticultural Science 67(5):619-626.*

A storage experiment was aimed at preventing low temperature storage disorders in nectarine fruits, of cvs July Red and Autumn Grand. Fruit was either cooled immediately after harvest or kept at 20-degrees-C for 48 h, before transfer to controlled atmosphere (CA) conditions at 0-degrees-C. Combinations of 0, 10, 15 and 20% CO2 with 8 and 16% O2 were assayed. The fruit was evaluated following cold storage, 31 days after harvest, and after four and eight days under 'shelf conditions'(ripening at 15-18-degrees-C). Warming of the fruit at 20-degrees-C before cold storage prevented woolliness in the absence of elevated CO2 levels but did not affect internal browning and increased reddish discoloration; further, it enhanced water loss and ripening, increasing fruit softening markedly. Conversely, high CO2 delayed fruit ripening in CA storage, keeping the fruit firmer, and preventing the development of woolliness, internal browning and reddish discoloration during ripening, the best results being mostly obtained with 20% CO2. O2 levels assayed did not show clear effects, but decreased O2 concentration in absence of high CO2 showed some benefit in 'July Red'. No deleterious effect of CO2 concentrations even as high as 20% could be detected. Thus, even though high CO2 in CA conditions showed promise for controlling disorders and preventing over-ripening, further work is needed on other cultivars, and lower O2 concentrations should be investigated before making a general recommendation.

KEYWORDS: INTERNAL BREAKDOWN, PEACHES, TEMPERATURES

1974

Retuerto, R., L. Rochefort, and F.I. Woodward. 1996. The influence of plant density on the responses of Sinapis alba to CO2 and windspeed. *Oecologia 108(2):241-251.*

Plants in nature live in populations of variable density, a characteristic which may influence individual plant responses to the environment. We investigated how the responses of Sinapis alba plants to different wind speeds and CO2 concentrations could be modified by plant density. In our wind- density experiment the expectation that mechanical and physiological effects of wind will be ameliorated by growing in high density, as a result of positive plant interactions, was realised. Although individual plants were smaller at higher densities, the effect of increasing windspeed was much less than at lower plant densities. A similar reduced sensitivity of individual plant growth under high densities was also observed under CO2 enrichment. When measured as a population or stand response, there was no effect of density on the CO2 responses, with all stands showing very similar increases in total biomass with CO2 enrichment. In the wind speed experiment, total biomass per stand increased significantly with density, although there was no effect of density on the wind speed response. Specific leaf area decreased with increasing wind speed and this response was significantly affected by the density at which the plants grew.

KEYWORDS: BIOMASS ALLOCATION, CANOPY STRUCTURE, CARBON DIOXIDE, GROWTH, LEAF-AREA, LIGHT, PHOTOSYNTHESIS, SIZE, WATER RELATIONS, WIND

1975

Retuerto, R., and F.I. Woodward. 1993. The influences of increased co2 and water-supply on growth, biomass allocation and water-use efficiency of sinapis-alba L grown under different wind speeds. *Oecologia 94(3):415-427.*

We examined how independent and interactive effects of CO2 concentrations, water supply and wind speed affect growth rates, biomass partitioning, water use efficiency, diffusive conductance and stomatal density of plants. To test the prediction that wind stress will be ameliorated by increased CO2 and/or by unrestricted water supply we grew Sinapis alba L. plants in controlled chambers under combinations of two levels of CO2 (350 ppmv, 700 ppmv), two water regimes and two wind speeds (0.3 ms-1, 3.7 ms-1). We harvested at ten different dates over a period of 60 days. A growth analysis was carried out to evaluate treatment effects on plant responses. Plants grown both in increased CO2 and in low wind conditions had significantly greater stem length, leaf area and dry weights of plant parts. Water supply significantly affected stem diameter, root weight and leaf area. CO2 enrichment significantly increased the rate of biomass accumulation and the relative ratio of biomass increase to leaf area expansion. High wind speed significantly reduced plant growth rates and the rate of leaf area expansion was reduced more than the rate of biomass accumulation. Regression analysis showed significant CO2 effects on the proportion of leaf and stem dry weight to total dry weight. A marked plant-age effect was dependent on water supply, wind speed and CO2 concentration. A reduced water supply significantly decreased the stomatal conductance, and water use efficiency significantly increased with a limited water supply, low wind and increased CO2. We found significant CO2 x wind effects for water diffusion resistance, adaxial number of stomata and water use efficiencies and significant wind x water effect for water use efficiency. In conclusion, wind stress was ameliorated by growing in unrestricted water but not by growing in increased CO2.

KEYWORDS: ATMOSPHERIC CARBON-DIOXIDE, DIFFERENT IRRADIANCE LEVELS, ECOSYSTEMS, ELEVATED CO2, ENRICHMENT, LEAF-AREA, LIQUIDAMBAR- STYRACIFLUA, PINUS-TAEDA SEEDLINGS, PLANT GROWTH, STOMATAL DENSITY

1976

Reuveni, J., and B. Bugbee. 1997. Very high CO2 reduces photosynthesis, dark respiration and yield in wheat. *Annals of Botany 80(4):539-546.*

Although terrestrial CO2 concentrations, [CO2], are not expected to reach 1000 mu mol mol(-1) for many decades, CO2 levels in closed systems such as growth chambers and glasshouses, can easily exceed this concentration. CO2 levels in life support systems in space can exceed 10 000 mu mol mol(- 1) (1 %). Here we studied the effect of six CO2 concentrations, from ambient up to 10000 mu mol mol(-1), on seed yield, growth and gas exchange of two wheat cultivars (USU-Apogee and Veery- 10). Elevating [CO2] from 350 to 1000 mu mol mol(-1) increased seed yield (by 33 %), vegetative biomass (by 25 %) and number of heads m(-2) (by 34 %) of wheal plants. Elevation of [CO2] from 1000 to 10000 mu mol mol(-1) decreased seed yield (by 37 %), harvest index (by 14%), mass per seed (by 9 %) and number of seeds per head (by 29 %). This very high [CO2] had a negligible, non-significant effect on vegetative biomass, number of heads m(-2) and seed mass per head. A sharp decrease in seed yield, harvest index and seeds per head occurred by elevating [CO2] from 1000 to 2600 mu mol mol(-1). Further elevation of [CO2] from 2600 to 10000 mu mol mol(-1) caused a further but smaller decrease. The effect of CO2 on both wheal cultivars was similar for all growth parameters. Similarly there were no differences in the response to high [CO2] between wheal grown hydroponically in growth chambers under fluorescent lights and those grown in soilless media in a glasshouse under sunlight and high pressure sodium lamps. There was no correlation between high [CO2] and ethylene production by flag leaves or by wheal heads. Therefore, the reduction in seed set in wheal plants is not mediated by ethylene. The photosynthetic rate of whole wheat plants was 8 % lower and dark respiration of the wheat heads 25 % lower when exposed to 2600 mu mol mol(- 1) CO2 compared to ambient [CO2]. It is concluded that the reduction in the seed set can be mainly explained by the reduction in the dark respiration in wheat heads, when most of the respiration is functional and is needed for seed development. (C) 1997 Annals of Botany Company.

KEYWORDS: CARBON DIOXIDE, ENHANCEMENT, ENRICHMENT, ETHYLENE PRODUCTION, GROWTH, INTACT SUNFLOWER PLANTS, LEAVES, LIGHT, PHYSIOLOGY, RELEASE

1977

Reuveni, J., J. Gale, and A.M. Mayer. 1993. Reduction of respiration by high ambient co2 and the resulting error in measurements of respiration made with o2 electrodes. *Annals of Botany 72(2):129-131.*

KEYWORDS: EFFLUX, ELEVATED CARBON-DIOXIDE, ENRICHMENT, GROWTH, LEAVES, PHOTOSYNTHESIS

1978

Reuveni, J., J. Gale, and M. Zeroni. 1997. Differentiating day from night effects of high ambient [CO2] on the gas exchange and growth of Xanthium strumarium L exposed to salinity stress. *Annals of Botany 79(2):191-196.*

Sodium chloride, at a concentration of 88 mol m(-3) in half strength Hoagland nutrient solution, increased dry weight per unit area of Xanthium strumarium L. leaves by 19%, and chlorophyll by 45% compared to plants grown without added NaCl at ambient (350 mu mol mol(-1)) CO2 concentration. Photosynthesis, per unit leaf area, was almost unaffected. Even so, over a 4-week period, growth (dry weight increment) was reduced in the salt treatment by 50%. This could be ascribed to a large reduction in leaf area (>60%) and to an approx. 20% increase in the rate of dark respiration (Rd). Raising ambient [CO2] from zero to 2000 mu mol mol(-1) decreased Rd in both control and salinized plants (by 20% at 1000, and by 50% at 2000 mu mol mol(-1) CO2 concentration) compared to Rd in the absence of ambient CO2. High night-time [CO2] had no significant effect on growth of non-salinized plants, irrespective of day-time ambient [CO2]. Growth reduction caused by salt was reduced from 51% in plants grown in 350 mu mol mol(-1) throughout the day, to 31% in those grown continuously

in 900 mu mol mol(-1) [CO2]. The effect of [CO2] at night on salinized plants depended on the daytime CO2 concentration. Under 350 mu mol mol(-1) day-time [CO2], 900 mu mol mol(-1) at night reduced growth over a 4-week period by 9% (P <0.05) and 1700 mu mol mol(-1) reduced it by 14% (P <0.01). However, under 900 mu mol mol(-1) day-time [CO2], 900 vs. 350 mu mol mol(-1) [CO2] at night increased growth by 17% (P <0.01). It is concluded that there is both a functional and an otiose (functionless) component to Rd, which is increased by salt. Under conditions of low photosynthesis (such as here, in the low day-time [CO2] regime) the otiose component is small and high night-time [CO2] partly suppresses functional Rd, thereby reducing salt tolerance. In plants growing under conditions which stimulate photosynthesis (e.g. with increased daytime [CO2]), elevated [CO2] at night suppresses mainly the otiose component of respiration, thus increasing growth. Consequently, in regions of adequate water and sunlight, the predicted further elevation of the world atmospheric [CO2] may increase plant salinity tolerance. (C) 1997 Annals of Botany Company.

KEYWORDS: DARK RESPIRATION RATE, ELEVATED CARBON-DIOXIDE, ENRICHMENT, LOLIUM-PERENNE, MAINTENANCE RESPIRATION, MATURE LEAVES, PHOTOSYNTHESIS, PLANTS, SELECTION, TEMPERATURE

1979

Reuveni, J., A.M. Mayer, and J. Gale. 1995. High ambient carbon-dioxide does not affect respiration by suppressing the alternative, cyanide-resistant pathway. *Annals of Botany 76(3):291-295.*

Total dark respiration (v(t)), cytochrome pathway (v(eyt)), alternative pathway (v(alt)) and residual (v(res)) respiration were measured in Lemna gibba plants, by the use of pathway inhibitors. NaCN was used to inhibit v(eyt) and SHAM (salicylhydroxamic acid) to inhibit v(alt). Residual respiration (v(res)) was about 5% of v(t). The effect of high (100 Pa) and low (0 Pa) carbon dioxide partial pressure ([CO2) on v(t), v(cyt) and v(alt) was determined from both CO2 efflux and O(2)uptake measurements. The higher [CO2] suppressed v(t) by about 30%. When respiration operated through the cytochrome pathway only. in the absence of v(alt), it was suppressed by about 12% as measured by the O-2 uptake of submerged Lemna fronds or by about 40% as measured by CO2 efflux from Boating fronds. The higher [CO2] treatment had only a small effect oil respiration, when v(alt) alone operated. There was no evidence of a specific suppression of the v(alt) pathway by high [CO2]. Succinic dehydrogenase activity of the mitochondria of roots of Medicago sativum was reduced by 18%, when the mitochondria were pre-treated with 120 as compared to 34 Pa [CO2]. There was no such effect on cytochrome c oxidase activity of mitochondria under the same conditions. It is concluded that there is no evidence for the hypothesis that the high [CO2] suppression of respiration is a result of a CO2 effect on the non- phosphorylating alternative respiration pathway. (C) 1995 Annals of Botany Company

KEYWORDS: DARK RESPIRATION, ELEVATED CO2, ENRICHMENT, GROWTH, INHIBITION, LEAVES, MITOCHONDRIA, OXIDASE, PLANT RESPIRATION, TEMPERATURE

1980

Rey, A., and P.G. Jarvis. 1997. Growth response of young birch trees (Betula pendula Roth.) after four and a half years of CO2 exposure. *Annals of Botany 80(6):809-816.*

A field experiment consisting of 18 birch trees grown in open top chambers in ambient and elevated CO2 concentrations was set up with the aim of testing whether the positive growth response observed in many short-term studies is maintained after several growing seasons. We present the results of growth and biomass after 4.5 years of CO2 exposure, one of the longest studies so far on deciduous tree species. We found that elevated CO2 led to a 58% increase in biomass at the end of the experiment. However, estimation of stem mass during the growing season showed that elevated CO2 did not affect relative growth rate during the fourth growing season, and therefore, that the large accumulation of biomass was the result of an early effect on relative growth rate in previous years. Trees grown in elevated CO2 invested more carbon into fine roots and had relatively less leaf area than trees grown in ambient CO2, In contrast with previous studies, acceleration of growth did not involve a significant decline in nutrient concentrations of any plant tissue. It is likely that increased fine root density assisted the trees in meeting their nutrient demands. Changes in the species composition of the ectomycorrhizal fungi associated with the trees grown in elevated CO2 in favour of late successional species supports the hypothesis of an acceleration of the ontogeny of the trees in elevated CO2. (C) 1997 Annals of Botany Company.

KEYWORDS: CARBON DIOXIDE, ELEVATED ATMOSPHERIC CO2, ENRICHMENT, GAS-EXCHANGE, LEAF ANATOMY, MINERAL NUTRITION, NUTRIENT STATUS, POPLAR CLONES, SEEDLINGS, SOUR ORANGE TREES

1981

Rey, A., and P.G. Jarvis. 1998. Long-term photosynthetic acclimation to increased atmospheric CO2 concentration in young birch (Betula pendula) trees. *Tree Physiology 18(7):441-450.*

To study the long-term response of photosynthesis to elevated atmospheric CO2 concentration in silver birch (Betula pendula Roth.), 18 trees were grown in the field in open-top chambers supplied with 350 or 700 mu mol mol(-1) CO2 for four consecutive growing seasons. Maximum photosynthetic rates, stomatal conductance and CO2 response curves were measured over the fourth growing season with a portable photosynthesis system. The photosynthesis model developed by Farquhar et al. (1980) was fitted to the CO2 response curves. Chlorophyll, soluble proteins, total nonstructural carbohydrates, nitrogen and Rubisco activity were determined monthly. Elevated CO2 concentration stimulated photosynthesis by 33% on average over the fourth growing season. However, comparison of maximum photosynthetic rates at the same CO2 concentration (350 or 700 mu mol mol(-1)) revealed that the photosynthetic capacity of trees grown in an elevated CO2 concentration was reduced. Analysis of the response curves showed that acclimation to elevated CO2 concentration involved decreases in carboxylation efficiency and RuBP regeneration capacity. No clear evidence for a redistribution of nitrogen within the leaf was observed. Down-regulation of photosynthesis increased as the growing season progressed and appeared to be related to the source-sink balance of the trees. Analysis of the main leaf components revealed that the reduction in photosynthetic capacity was accompanied by an accumulation of starch in leaves (100%), which was probably responsible for the reduction in Rubisco activity (27%) and to a lesser extent for reductions in other photosynthetic components: chlorophyll (10%), soluble protein (9%), and N concentrations (12%) expressed on an area basis. Despite a 21% reduction in stomatal conductance in response to the elevated CO2 treatment, stomatal limitation was significantly less in the elevated, than in the ambient, CO2 treatment. Thus, after four growing seasons exposed to an elevated CO2 concentration in the field, the trees maintained increased photosynthetic rates, although their photosynthetic capacity was reduced compared With trees grown in ambient CO2.

KEYWORDS: ELEVATED CARBON-DIOXIDE, FOLIAR GAS-EXCHANGE, GROWTH, LEAF, PINUS TAEDA L, PLANTS, RESPONSES, RUBISCO, SINK REGULATION, STOMATAL CONDUCTANCE

1982

Rey, P., F. Eymery, and G. Peltier. 1990. Effects of CO2-enrichment and of aminoacetonitrile on growth and photosynthesis of photoautotrophic calli of Nicotiana plumbaginifolia. *Plant Physiology 93(2):549-554.*

1983

Reyenga, P.J., S.M. Howden, H. Meinke, and G.M. McKeon. 1999. Modelling global change impacts on wheat cropping in south-east Queensland, Australia. *Environmental Modelling & Software 14(4):297-306.*

The wheat module, I-WHEAT, from the APSIM cropping system model was used to investigate the impacts of changes in atmospheric CO2 concentrations on wheat crops by modifying radiation use efficiency, transpiration efficiency, specific leaf area and critical nitrogen concentrations. The effects of several combinations of atmospheric CO2, climate change and crop adaptation strategies on wheat production in the Burnett region were studied. Mean wheat yields were increased under doubled CO2, with the response relative to ambient CO2 greatest in dry years. Higher temperatures under the climate change scenarios moderated the yield gains achieved with increasing CO2 and in some instances reversed them under the reduced rainfall scenario. The status of the region as a producer of prime hard wheat may be at risk due to reduced grain protein levels under doubled CO2 and the increased likelihood of "heat shock" in the climate scenarios used.

KEYWORDS: AMBIENT ATMOSPHERE, ATMOSPHERIC CO2 CONCENTRATIONS, CARBON-DIOXIDE ENRICHMENT, ELEVATED CO2, HEAT-SHOCK, PLANT GROWTH, PROTEIN ACCUMULATION, RESPONSES, TEMPERATURE, WATER-USE EFFICIENCY

1984

Reynolds, J.F., J.L. Chen, P.C. Harley, D.W. Hilbert, R.L. Dougherty, and J.D. Tenhunen. 1992. Modeling the effects of elevated co2 on plants - extrapolating leaf response to a canopy. *Agricultural and Forest Meteorology 61(1-2):69-94.*

The response of canopies to short-duration exposure to elevated CO2 was examined by using a detailed submodel of single-leaf ps exchange combined with a model of canopy structure and light penetration. The leaf model included a mechanistic ps exchange model and leaf energy balance equations, and the canopy model included a detailed description of spatial variability in environmental conditions within the canopy. The structure of the canopy model was designed to facilitate implementation of different leaf aggregation schemes. To compare six aggregation methods of increasing simplicity, daily carbon gain, and water use were simulated for Quercus coccifera under current ambient and future doubled CO2. Analyses of simulated canopy responses confirmed the importance of including (1) leaf energy balance and (2) distinguishing between sunlit and shaded leaves. A multi-layer canopy model with Gaussian integration for sunlit leaves and a single leaf class for shaded leaves in each layer gave excellent results. A multi-layer model with one shaded and one sunlit leaf class gave a reasonable approximation, and the single-layer model with one sunlit and one shaded leaf class resulted in errors of up to 15%. Vertical gradients in leaf nitrogen content and leaf and stem area index had greater effects on canopy assimilation and transpiration than did gradients of stem or leaf inclination or leaf width. However, predictions of the relative response of CO2 assimilation and transpiration to doubled CO2 are rather robust and were not greatly affected by simplifications of the canopy model.

KEYWORDS: ALLOCATION, C-3, CARBON DIOXIDE, CLIMATE, ECOSYSTEMS, ENRICHMENT, GROWTH, NITROGEN, PHOTOSYNTHESIS, WATER-USE

1985

Rice, C.W., F.O. Garcia, C.O. Hampton, and C.E. Owensby. 1994. Soil microbial response in tallgrass prairie to elevated co2. *Plant and Soil 165(1):67-74.*

Terrestrial responses to increasing atmospheric CO2 are important to the global carbon budget. Increased plant production under elevated CO2 is expected to increase soil C which may induce N limitations. The objectives of this study were to determine the effects of increased CO2 on 1) the amount of carbon and nitrogen stored in soil organic matter and microbial biomass and 2) soil microbial activity. A tallgrass prairie ecosystem was exposed to ambient and twice-ambient CO2 concentrations in open-top chambers in the field from 1989 to 1992 and compared to unchambered ambient CO2 during the entire growing season. During 1990 and 1991, N fertilizer was included as a treatment. The soil microbial response to CO2 was measured during 1991 and 1992. Soil organic C and N were not significantly affected by enriched atmospheric CO2. The response of microbial biomass to CO2 enrichment was dependent upon soil water conditions. In 1991, a dry year, CO2 enrichment significantly increased microbial biomass C and N. In 1992, a wet year, microbial biomass C and N were unaffected by the CO2 treatments. Added N increased microbial C and N under CO2 enrichment. Microbial activity was consistently greater under CO2 enrichment because of better soil water conditions. Added N stimulated microbial activity under CO2 enrichment. Increased microbial N with CO2 enrichment may indicate plant production could be limited by N availability. The soil system also could compensate for the limited N by increasing the labile pool to support increased plant production with elevated atmospheric CO2. Longer-term studies are needed to determine how tallgrass prairie will respond to increased C input.

KEYWORDS: ATMOSPHERIC CO2, BIOMASS, CARBON DIOXIDE, DYNAMICS, ECOSYSTEMS, ENRICHMENT, GRASSLAND SOILS, MODEL, NITROGEN, ORGANIC-MATTER

1986

Riedo, M., D. Gyalistras, A. Fischlin, and J. Fuhrer. 1999. Using an ecosystem model linked to GCM-derived local weather scenarios to analyse effects of climate change and elevated CO2 on dry matter production and partitioning, and water use in temperate managed grasslands. *Global Change Biology 5(2):213-223.*

Local effects of climate change (CC) and elevated CO2 (2 x CO2, 660 mu mol mol(-1)) on managed temperate grasslands were assessed by forcing a dynamic ecosystem model with weather scenarios. The aims of the study were to compare the relative importance of individual and combined effects of CC, 2 x CO2, and photosynthetic acclimation, and to assess the importance of local site conditions. The model was driven by hourly means for temperature (T), precipitation (P), global radiation (G), vapour pressure (VP), and wind speed (U). Local climate scenarios were derived by statistical downscaling techniques from a 2 x CO2 simulation with the General Circulation Model of the Canadian Climate Centre (CCC-GCMII). Simulations over 14 growing seasons to account for year-to-year variability of climate were carried out for a low, relatively dry site, and a high, more humid site. At both sites, shoot dry matter responded positively to 2 x CO2 with the site at low elevation being more sensitive than the higher site. The effect of assumed changes in climate was negative at the lower, but positive at the higher site. Shoot dry matter was more sensitive to the effects of 2 x CO2 than to CC. Both effects combined increased shoot dry matter by up to 20%. This was attributed to direct effects of 2 x CO2 and increased T,and indirect stimulation via increased soil N availability. Biomass partitioning to roots increased with 2 x CO2 but decreased with CC, while an intermediate response resulted from the combination. Leaf area index (LAI) increased under 2 x CO2, but not enough to compensate fully for a decrease in leaf conductance. Under the 2 x CO2 scenario

evapotranspiration (ET) decreased, but increased under CC. Photosynthetic acclimation reduced the effect of 2 x CO2 on shoot growth, but had little effect on ET. The seasonal water use efficiency (WUE) was improved under 2 x CO2, and reduced under CC. With the combination of both factors, the change was small but still positive, especially at the high elevation site with more favourable soil water conditions. This reflects the stronger positive yield response in combination with a smaller increase in ET under cooler, more humid conditions. The results for the combination of factors suggest that except for shoot growth, effects of 2 x CO2 and CC tend to offset each other. While CC determines the sign of the ET response, the sign of the biomass response is determined by 2 x CO2. The results highlight the importance of a site-specific analysis of ecosystem responses by using a flexible approach based on a combination of state- of-the-art downscaling, spatially resolved data sets, and a mechanistic model to obtain quantitative and reproducible assessments of climate change impacts at the ecosystem level.

KEYWORDS: ATMOSPHERIC CO2, DAILY PRECIPITATION, GENERAL-CIRCULATION MODEL, GROWTH, LOLIUM-PERENNE L, RESPONSES, ROOT, SENSITIVITY ANALYSIS, SIMULATION, TRIFOLIUM-REPENS L

1987

Riedo, M., D. Gyalistras, A. Grub, M. Rosset, and J. Fuhrer. 1997. Modelling grassland responses to climate change and elevated CO2. *Acta Oecologica-International Journal of Ecology 18(3):305-311.*

A mechanistic model for productive grassland was used to simulate the annual production of above-and belowground plant biomass in relation to fluxes of C, N, and water, and to test the sensitivity of yield, shoot/root ratio, evapotranspiration, and water use efficiency (WUE) to climate change scenarios (CC) and to elevated CO2 (2 x CO2) with or without consideration oi photosynthetic acclimation of the plants. Validation with data from two Swiss sites revealed satisfactory agreement between simulation and measurement for yield, energy fluxes, and N- dynamics. Local weather scenarios were derived from the results of two General Circulation Models (GCM) for 2 x CO2 by a statistical down-scaling procedure. Biomass production changed by a maximum of 8% in response to CC without 2 x CO2 effects, by 1-17% in response to 2 x CO2 alone, and by 6-20% in response to the combination of CC and 2 x CO2. With plant acclimation, biomass Production increased only up to 8% with elevated CO2, as compared to a maximum increase of 20% in the absence of plant acclimation. Reduced yield with CC was obtained for sites with low soil water holding capacity. Decreased evapotranspiration and increased WUE with 2 x CO2 were partially offset by CC. The simulations indicated that productivity of managed grassland is sensitive to different assumptions about changes in climate, CO2 concentration, and photosynthetic acclimation, and that the effects of elevated CO2 are modified by CC and depend on local soil conditions.

KEYWORDS: CARBON, GENERAL-CIRCULATION MODEL, SOIL

1988

Righetti, B., E. Magnanini, and F. Rossi. 1993. Photosynthetic carbon-dioxide uptake and oxygen accumulation during in-vitro culture of actinidia-deliciosa CV tomuri. *Environmental and Experimental Botany 33(4):523-528.*

Proliferating cultures of Actinidia deliciosa cv Tomuri were grown in vitro under a photosynthetic photon flux density (PPFD) of 120 mumol m2/s. Some jars were daily enriched with 2000 mul/l CO2 administered at the end of the dark period. Head space analysis revealed that CO2 accumulated up to 9500 mul/l during the dark period and was drastically reduced by photosynthetic activity to 150-200 mul/l during the photoperiod without any significant difference between CO2-enriched and non-enriched cultures. Oxygen concentration assayed at the end of the photoperiod showed a steady increase during the 44 days of culture and was not reduced to atmospheric values by respiratory processes during the dark period. CO2 enrichment enhanced O2 production and accumulation to 32.5% at the end of the culture period. Oxygen photoreduction and its photo- oxidative damage to green tissue cells are discussed.

KEYWORDS: ACCLIMATION, ATMOSPHERIC CO2, ENRICHMENT, EXCHANGE, GROWTH, LIGHT, PLANTS, STARCH, STRESS, TOXICITY

1989

Righetti, B., D.M. Reid, and T.A. Thorpe. 1996. Growth and tissue senescence in Prunus avium shoots grown in vitro at different CO2/O-2 ratios. *In Vitro Cellular & Developmental Biology-Plant 32(4):290-294.*

The rate of metabolism and biosynthetic processes make in vitro cultures very sensitive to environmental changes, and therefore subject to physiological and morphological alterations leading to senescence in the short term. The effects of three different calibrated atmospheric compositions were studied during in vitro culture of Prunus avium shoots. At 0.034% CO2-21% O-2 (vol/vol), which stimulate the natural atmosphere, the highest growth rate and chlorophyll content were recorded. When grown at 0.09% CO2-8% O-2 (vol/vol), a favorable condition for photosynthesis and growth, cultures showed a higher percentage of dry matter and elevated ethylene production, but total chlorophyll was lower. These shoots were also highly lignified and fibrous with red pigmentation along the leaves and stems. At 0% CO2-21% O-2 (vol/vol), in contrast, growth and ethylene formation were inhibited; chlorophyll content was lowest in comparison with the other two environmental conditions, hut regreening of tissues was observed after the first half of the culture period. Senescence symptoms, as indicated by decreased chlorophyll, appeared after about 18 d of culture for tissues grown in CO2-containing atmospheres. These experiments provided evidence that in CO2-enriched cultures biomass production steadily increased even when chlorophyll decreased. A possible role of CO2 in promoting tissue-senescence through activation of photooxidative events and ethylene synthesis is discussed.

KEYWORDS: ACTIVATION, BEAN-LEAVES, CARBON DIOXIDE, CO2- ENRICHMENT, CROP RESPONSES, LONG-TERM ACTION, NET PHOTOSYNTHETIC RATE, OXYGEN CONCENTRATION, PHOTORESPIRATION, TOXICITY

1990

Rigler, E., and S. Zechmeister-Boltenstern. 1998. Influence of nitrogen and carbon dioxide on ethylene and methane production in two different forest soils. *Microbiological Research 153(3):227-237.*

The impact of nitrogen and CO, on ethylene and methane production was investigated in two different forest soils. The soils were adjusted to a water tension of 30 kPa. Nitrogen was added in the form of KNO3 or (NH4)(2)SO4 and CO2 was added in 5 different concentrations. To half of the samples, C2H2 was added to inhibit ethylene uptake. After 0, 24, and 96 hours, ethylene and methane concentrations were measured by gas chromatography. Ethylene net production increased with increasing N and CO2 concentrations. In the presence of acetylene, ethylene production was unaffected by the investigated amendments. Therefore, we suppose that the increasing ethylene net production rates are due to decreasing ethylene uptake rates. In the deciduous forest soil, there was no ethylene net production rate, as uptake rates exceeded production rates. Methane net production rates in the spruce forest soil increased with increasing N additions possibly due to a lowered C:N ratio and a decreased methane oxidation. Ethylene production rates in the presence

of acetylene were slightly enhanced. In the deciduous forest soil, methane uptake rates decreased with nitrogen possibly due to the inhibition of the methanemonooxygenase. CO2 seemed to increase methane production in the presence of acetylene but had no significant effect on methane net production. Acetylene might serve as a substrate for methanogenesis.

KEYWORDS: ACCUMULATION, ACETYLENE-REDUCTION ASSAY, BIOSYNTHESIS, CONSUMPTION, FERTILIZERS, INHIBITION, MICROORGANISMS, NADH-FE(III)EDTA OXIDOREDUCTASE, NITRATE, RESPONSES

1991

Rigler, E., and S. Zechmeister-Boltenstern. 1999. Oxidation of ethylene and methane in forest soils - effect of CO2 and mineral nitrogen. *Geoderma 90(1-2):147-159.*

The influence of inorganic nitrogen and CO2 on microbial C2H4 and CH4 consumption was evaluated in two forest soils (montane spruce forest and colline deciduous forest) under laboratory conditions at 25 degrees C. The soils were adjusted to a water tension of - 30 kPa. Nitrogen was added as KNO3 or (NH4)(2)SO4, while CO2 enrichment ranged from 1-20%. At 0, 24, and 96 h, the amounts of CH4 and C2H4 consumed were determined. In both soils, we observed a parallel response of C2H4 and CH4 to all kinds and concentrations of amendments, plausibly due to co- metabolism of C2H4 by either methanotrophs or nitrifiers. Ammonium-N inhibited hydrocarbon oxidation in the deciduous forest soil, but promoted it in the acidic spruce forest soil. Ammonium addition narrowed the C:N ratio of the spruce forest soil which was characterized by low pH but high humus content. Therefore, the general living conditions for microorganisms might have been improved. Conversely, NO3- inhibited hydrocarbon oxidation in both soils, here a non-specific ion toxicity ('salt-effect') is discussed. CO2 also had an inhibitory effect on hydrocarbon microbial uptake at high concentrations, with its production increasing at elevated CO2 levels. We conclude that the impact of nitrogen inputs and of enhanced CO2 on the sink strength for hydrocarbons depends on the amount and the kind of addition as well as on soil type. (C) 1999 Elsevier Science B.V. All rights reserved.

KEYWORDS: AMMONIUM INHIBITION, ATMOSPHERIC METHANE, BACTERIA, CAPACITY, CONSUMPTION, HYDROCARBONS, METABOLISM, N-FERTILIZATION, NITRIFICATION, TEMPERATURE

1992

Riis, T., and K. SandJensen. 1997. Growth reconstruction and photosynthesis of aquatic mosses: Influence of light, temperature and carbon dioxide at depth. *Journal of Ecology 85(3):359-372.*

1 The mosses Sphagnum subsecundum and Drepanocladus exannulatus dominate the vegetation in the oligotrophic, softwater Lake Grane Langso, Denmark, even at great depths where light and temperature are low. We used seasonal changes in morphology to reconstruct the annual growth and the longevity of the mosses and measurements of photosynthesis and respiration to evaluate the importance of light, temperature and CO2 for the growth patterns at depth in the lake. 2 The reconstruction technique revealed that the mosses had a relatively fast growth rate (90- 250 mm shoot(-1) year(-1)) and were short lived (0.7-2.9 years). The shoots of both moss species grew faster in deep than in shallow water. Growth experiments in summer confirmed that Sphagnum grew more slowly and decayed more rapidly in shallow than in deep water. 3 Fast growth of mosses in deep waters can be accounted for by lower temperature, extensive CO2 supersaturation and nutrient enrichment in the hypolimnion during summer stratification. Maximum rate of light-saturated photosynthesis in July was 3.3-fold higher and of dark respiration 1.3-fold lower in Sphagnum from 9.5m incubated at the ambient 8 degrees C than in Sphagnum from 0.7m incubated at 20 degrees C. The net daily carbon fixation was greater in deep than in shallow water despite the much lower irradiance at depth. Extensive CO2 supersaturation stimulated photosynthesis several-fold relative to the rates observed in air-saturated water. Tissues of Sphagnum were richer in nitrogen in deep than in shallow water during summer, but the importance of nutrient availability to annual moss growth remains unclear. 4 Reconstruction techniques are recommended for comparative studies on annual and interannual growth patterns of mosses within lakes and among lakes of different altitude, latitude and water chemistry. This information can be based on just a single collection and can therefore include remote sites with adverse climate.

KEYWORDS: ANTARCTIC LAKES, BENTHIC PLANTS, FONTINALIS-ANTIPYRETICA, IRRADIANCE, MACROPHYTE COMMUNITIES, POPULATION-DYNAMICS, PRODUCTION ECOLOGY, STRATEGIES, SWEDISH LAPLAND, TUNDRA PLANTS

1993

Rillig, M.C., and M.F. Allen. 1998. Arbuscular mycorrhizae of Gutierrezia sarothrae and elevated carbon dioxide: Evidence for shifts in C allocation to and within the mycobiont. *Soil Biology and Biochemistry 30(14):2001-2008.*

In a complete 2 x 2 factorial greenhouse experiment we examined the responses of arbuscular mycorrhizal (AM) and non- mycorrhizal fungi to Gutierrezia sarothrae shrubs grown in elevated atmospheric carbon dioxide (750 mu l l(-1)) and fertilized with N. AM percent infection did not change significantly with elevated CO2, but arbuscular infection increased 14-fold in the low-N treatment. Extraradical hyphal length increased on an absolute basis in elevated CO2, and also per infected root length. In the high-N treatments, increasing CO2 caused a decrease in hyphal length per infected root length, and an increase in vesicular infection. There was a significant positive response of AM infection intensity to increasing CO2 for the high N treatment, and a similar trend in the low N treatment. Infection intensity was positively correlated with arbuscular infection and with vesicular infection. Nonmycorrhizal fungi did not respond to any of the treatment combinations, as measured by percent root infection and external hyphal length. Our results indicate that C allocation to the AM fungi was increased in elevated CO2, and that the mycobiont in turn increased C allocation to external hyphae. (C) 1998 Elsevier Science Ltd. All rights reserved.

KEYWORDS: ATMOSPHERIC CO2, COLONIZATION, ENRICHMENT, FUNGI, HYPHAE, RESPONSES, RHIZOSPHERE, ROOTS, SOIL

1994

Rillig, M.C., and M.F. Allen. 1999. What is the role of arbuscular mycorrhizal fungi in plant-to- ecosystem responses to Elevated atmospheric CO2? *Mycorrhiza 9(1):1-8.*

We advocate the concept of an arbuscular mycorrhiza (AM) as a temporally and spatially complex symbiosis representing a suite of hosts and fungi, as against the more traditional "dual organism" view. We use the hierarchical framework presented in Fig. 1 as a basis for organizing many unanswered questions, and several questions that have not been asked, concerning the role of AM in responses to elevated atmospheric CO2. We include the following levels: plant host, plant population, plant community, functional group and ecosystem. Measurements of the contributions of AM fungi at the various levels require the use of different response variables. For example, hyphal nutrient translocation rates or percent AM root infection may be important measures at the individual plant level, but hyphal biomass or glomalin production and turnover are more relevant at the ecosystem level. There is a discrepancy

between our knowledge of the multifaceted role of AM fungi in plant and ecosystem ecology and most of the current research aimed at elucidating the importance of this symbiosis in global-change scenarios. Our framework for more integrated and multifactorial research on mycorrhizal involvement in regulating CO2 responses may also serve to enhance communication between researchers working at different scales on large global-change ecosystem projects.

KEYWORDS: BIOMASS PRODUCTION, BOUTELOUA-GRACILIS, CARBON DIOXIDE, COLONIZATION, LITTER DECOMPOSITION, ROOTS, SOIL BIOTA, SYMBIOTIC N-2 FIXATION, TRIFOLIUM-REPENS L, WATER RELATIONS

1995

Rillig, M.C., M.F. Allen, J.N. Klironomos, N.R. Chiariello, and C.B. Field. 1998. Plant species-specific changes in root-inhabiting fungi in a California annual grassland: responses to elevated CO2 and nutrients. *Oecologia 113(2):252-259.*

Five co-occurring plant species from an annual mediterranean grassland were grown in monoculture for 4 months in pots inside open-top chambers at the Jasper Ridge Biological Preserve (San Mateo County, California). The plants were exposed to elevated atmospheric CO2 and soil nutrient enrichment in a complete factorial experiment. The response of root-inhabiting non- mycorrhizal and arbuscular mycorrhizal fungi to the altered resource base depended strongly on the plant species. Elevated CO2 and fertilization altered the ratio of non-mycorrhizal to mycorrhizal fungal colonization for some plant species, but not for others. Percent root infection by non-mycorrhizal fungal increased by over 500% for Linanthus parviflorus in elevated CO2, but decreased by over 80% for Bromus hordeaceus. By contrast, the mean percent infection by mycorrhizal fungi increased in response to elevated CO2 for all species, but significantly only for Avena barbata and B. hordeaceus. Percent infection by mycorrhizal fungi increased, decreased, or remained unchanged for different plant hosts in response to fertilization. There was evidence of a strong interaction between the two treatments for some plant species and non- mycorrhizal and mycorrhizal fungi. This study demonstrated plant species-and soil fertility-dependent shifts in belowground plant resource allocation to different morphogroups of fungal symbionts. This may have consequences for plant community responses to elevated CO2 in this California grassland ecosystem.

KEYWORDS: AMMONIUM-SULFATE, ARBUSCULAR MYCORRHIZAL FUNGI, ATMOSPHERIC CARBON-DIOXIDE, COLONIZATION, COMMUNITIES, ENRICHMENT, FEEDBACK, INFECTION, NITRATE, RHIZOSPHERE

1996

Rillig, M.C., M.F. Allen, J.N. Klironomos, and C.B. Field. 1998. Arbuscular mycorrhizal percent root infection and infection intensity of Bromus hordeaceus grown in elevated atmospheric CO2. *Mycologia 90(2):199-205.*

Using Bromus hordeaceus, a grass from a Mediterranean annual grassland in California, we measured changes in infection intensity, rather than the more traditional % root infection, as an indicator of response to elevated atmospheric CO2 and soil nutrient enrichment. Intensity was measured as the number of intraradical hyphae intersecting a microscope cross-hair for specific root diameter size classes. We found an increase in intensity of infection when plants were exposed to elevated CO2, and we found a decrease in infection intensity when plants were fertilized. This finding is significant in that it provides evidence for an increase in carbon allocation to the mycobiont under elevated CO2 even in the absence of change in percent infection, or mycorrhizal root length. Previous studies may therefore have overlooked an important response of arbuscular mycorrhizal fungi to this treatment, leading to an underestimation of the importance of mycorrhizae under elevated CO2. Infection intensity may also change in response to many other treatments and environmental variables that the symbiosis is exposed to, high-lighting the potential usefulness of intensity as a response variable in mycorrhizal research.

KEYWORDS: CARBON, COLONIZATION, COTTON, ENRICHMENT, PHOTOSYNTHESIS, PLANTS, RESPONSES, RHIZOSPHERE

1997

Rillig, M.C., C.B. Field, and M.F. Allen. 1999. Fungal root colonization responses in natural grasslands after long-term exposure to elevated atmospheric CO2. *Global Change Biology 5(5):577-585.*

Arbuscular mycorrhizae, ubiquitous mutualistic symbioses between plant roots and fungi in the order Glomales, are believed to be important controllers of plant responses to global change, in particular to elevated atmospheric CO2. In order to test if any effects on the symbiosis can persist after long-term treatment, we examined root colonization by arbuscular mycorrhizal (AM) and other fungi of several plant species from two grassland communities after continuous exposure to elevated atmospheric CO2 for six growing seasons in the field. For plant species from both a sandstone and a serpentine annual grassland there was evidence for changes in fungal root colonization, with changes occurring as a function of giant host species. We documented decreases in percentage nonmycorrhizal fungal root colonization in elevated CO2 for several plant species. Total AM root colonization (%) only increased significantly for one out of the five plant species in each grassland. However, when dividing AM fungal hyphae into two groups of hyphae (fine endophyte and coarse endophyte), we could document significant responses of AM fungi that were hidden when only total percentage colonization was measured. We also documented changes in elevated CO2 in the percentage of root colonized by both AM hyphal types simultaneously. Our results demonstrate that changes in fungal root colonization can occur after long-term CO2 enrichment, and that the level of resolution of the study of AM fungal responses may have to be increased to uncover significant changes to the CO2 treatment. This study is also one of the first to document compositional changes in the AM fungi colonizing roots of plants grown in elevated CO2. Although it is difficult to relate the structural data directly to functional changes, possible implications of the observed changes for plant communities are discussed.

KEYWORDS: ARBUSCULAR MYCORRHIZAL FUNGI, BOUTELOUA-GRACILIS, ENRICHMENT, GROWTH, INFECTION, SYSTEM, TREE

1998

Rillig, M.C., C.B. Field, and M.F. Allen. 1999. Soil biota responses to long-term atmospheric CO2 enrichment in two California annual grasslands. *Oecologia 119(4):572-577.*

Root, arbuscular-mycorrhizal (AM), soil faunal (protozoa and microarthropods), and microbial responses to field exposure to CO2 for six growing seasons were measured in spring 1997 in two adjacent grassland communities. The grasslands showed contrasting root responses to CO2, enrichment: whereas root length was not affected in the sandstone grassland, it was greater in the serpentine grassland, as was specific root length. AM fungal hyphal lengths were greater in the sandstone, but were unaffected in the serpentine community. This lent support to the hypothesis that there may be a tradeoff in resource allocation to more fine roots or greater mycorrhizal extraradical hyphal length. AM root infection was greater in both communities at elevated CO2, as was the proportion of roots containing arbuscules. Our data on total hyphal lengths, culturable and active fungi, bacteria, and protozoa supported the hypothesis that the fungal food chain was more strongly stimulated than the bacterial chain. This study is one of the first to test

these hypotheses in natural multi-species communities in the field.

KEYWORDS: ARBUSCULAR MYCORRHIZAL FUNGI, CARBON DIOXIDE, COMMUNITIES, ECOSYSTEMS, ELEVATED CO2, GROWTH, PASTURE, RHIZOSPHERE, SYSTEMS, TALLGRASS PRAIRIE

1999

Rillig, M.C., K.M. Scow, J.N. Klironomos, and M.F. Allen. 1997. Microbial carbon-substrate utilization in the rhizosphere of Gutierrezia sarothrae grown in elevated atmospheric carbon dioxide. *Soil Biology and Biochemistry 29(9-10):1387-1394.*

Differences in rhizosphere microbial community function in response to Gutierrezia sarothrae plants grown in elevated CO2 (750 mu l l(-1)) and fertilized with nitrogen were studied using the Biolog microplate analysis of sole C substrate utilization. Compared to ambient CO2 under elevated CO2, polymers were more slowly oxidized by the microbial community, amides showed no change in usage, and all other substrate groups were more rapidly utilized, although there was no significant change in the number of viable bacteria. No microbial community responses to N fertilization were detected. The results indicate that potential functional changes in the soil microbial community in response to elevated CO2 have to be taken into account in future experiments. Differential use of rhizo-deposits in elevated CO2 may have important consequences for biogeochemistry and plant growth. (C) 1997 Elsevier Science Ltd.

KEYWORDS: CO2, COMMUNITIES, DECOMPOSITION, DIVERSITY, FEEDBACK, LEAF LITTER, PATTERNS, RESPONSES, ROOTS

2000

Ringelberg, D.B., J.O. Stair, J. Almeida, R.J. Norby, E.G. ONeill, and D.C. White. 1997. Consequences of rising atmospheric carbon dioxide levels for the belowground microbiota associated with white oak. *Journal of Environmental Quality 26(2):495-503.*

The consequences for belowground microbiota under conditions of rising atmospheric CO2 are largely unknown. In this research we examined the microbiota associated with white oak (Quercus alba L.). It was our hypothesis that an increase in CO2 level would induce a change in the rhizosphere-associated microbial abundance and community composition. To provide an in situ estimation of microbial abundance and community composition, ester-linked polar lipid fatty acid (PLFA) technology was utilized. This technology, based on the quantitative measurement of membrane lipid fatty acids, has been utilized in the accurate identification and description of bacterial isolates and communities. Initial experiments demonstrated that a clear distinction in lipid patterns and microbial biomass existed between sterile roots and those of roots containing an associated viable microbiota. Statistical approaches were then used to determine what differences existed between individual PLFA and PLFA patterns obtained from white oak fine roots and bulk soils. An analysis of variance (ANOVA) showed significant differences to exist in the relative percentages of individual prokaryotic PLFA collected under ambient vs. elevated CO2 and between those associated with fine roots and bulk soils. Multivariate statistics showed distinct differences in the patterns of prokaryotic PLFA detected in the rhizosphere vs. the surrounding bulk soil, but did not identify differences related to elevated CO2 exposures. An artificial neural network recognized PLFA patterns unique to three different CO2 exposures: similar to 35, similar to 50, and similar to 65 Pa. Results of the three statistical tests were viewed as supportive of the hypothesis describing significant differences in individual PLFA and patterns of PLFA as a result of elevated CO2 exposure.

KEYWORDS: BIOMASS, ELEVATED CO2, ENRICHMENT, FATTY-ACIDS, GROWTH, MYCORRHIZAL COLONIZATION, PLANT-RESPONSES, POLY BETA HYDROXYBUTYRATE, QUERCUS-ALBA, RHIZOSPHERE

2001

RiviereRolland, H., P. Contard, and T. Betsche. 1996. Adaptation of pea to elevated atmospheric CO2: Rubisco, phosphoenolpyruvate carboxylase and chloroplast phosphate translocator at different levels of nitrogen and phosphorus nutrition. *Plant, Cell and Environment 19(1):109-117.*

Resource allocation in high CO2 was studied with respect to plant nutrition. Pea (Pisum sativum) was grown in CO2-enriched air (1000 cm(3) m(-3) CO2) during the entire vegetative phase, or grown in ambient air (340 cm(3) m(-3) CO2), with different levels of nitrogen or phosphorus supply. Rubisco specific activity, abundance and small subunit transcript levels were unaltered at high N but declined at reduced N depending upon the degree of N deprivation. It is proposed that (a) a threshold value for the N status occurs in pea above which Rubisco is not down-regulated by high CO2 and (b) a high leaf level of soluble carbohydrates is not a sufficient condition to down-regulate Rubisco in high CO2. Phesphoenolpyruvate (PEP) carboxylase decreased, and chloroplast phosphate (P)- translocator increased, in high CO2. In contrast to Rubisco, down-regulation of PEP carboxylase was alleviated by low N and enhanced by low P. The increase in the P-translocator was little affected by N but was accentuated by low P. The increase in the P-translocator is considered to be one way of alleviating low P conditions in the chloroplast and thus re- balancing carbon partitioning between starch and soluble carbohydrates and amino acids. It is proposed that acclimation of PEP carboxylase and P-translocator reflects adaptation to metabolic perturbations caused by high CO2.

KEYWORDS: ANTISENSE RBCS, C-3 PLANTS, CARBON DIOXIDE, CELLS, GROWTH, LIGHT, OXYGENASE, PHOTOSYNTHESIS, SINK REGULATION, TRIFOLIUM-SUBTERRANEUM L

2002

Roberntz, P. 1999. Effects of long-term CO2 enrichment and nutrient availability in Norway spruce. I. Phenology and morphology of branches. *Trees-Structure and Function 13(4):188-198.*

Branches of 30-year-old Norway spruce [Picea abies (L.) Karst.] trees were enclosed in ventilated, transparent plastic bags and flushed with air containing ambient (A approximate to 370 mu mol CO2 mol(-1)) or ambient plus 340 mu mol CO2 mol(-1) (EL). Light-saturated photosynthesis was on average 56% higher in EL compared to A. Branch phenology and morphology were strongly related to nitrogen concentration (mg g(-1) dry mass) in the foliage and to elevated temperatures in the bags, but no direct effect of EL was found. In 1995, budbreak occurred on average 4 days earlier in the bags compared to the control branches, which was partly explained by the temperature elevation in the bags. No nutrient or EL effect on budbreak was found. Increases in temperature and nitrogen supply increased shoot growth: together they explained 76% of the variation in the extension rate, 63% of the variation in extension duration and 65% of the variation in final length of leading shoots. Shoot morphology was altered both by increased nitrogen availability and by the enclosure induced environmental changes inside the bags, leading to reduced mutual shading between needles. Specific needle area (SNA) was lower in EL, but this was related to lower nitrogen concentrations. Total dry mass of the branches was unaffected by EL. It is concluded that treating individual branches of Norway spruce with elevated CO2 does not increase branch growth. The nutrient status of the branch and climate determine its growth, i.e, its sink strength for carbon. Increased export of carbohydrates to the rest of the tree is probable in EL treated branches.

KEYWORDS: ABIES AMABILIS, CARBON DIOXIDE, ELEVATED CO2, GROWTH, LOBLOLLY-PINE TREES, NET PHOTOSYNTHESIS, NUTRITION, PICEA-SITCHENSIS, RESPONSES, STOMATAL CONDUCTANCE

2003

Roberntz, P., and S. Linder. 1999. Effects of long-term CO2 enrichment and nutrient availability in Norway spruce. II. Foliar chemistry. *Trees-Structure and Function 14(1):17-27.*

Branches on 30-year-old Norway spruce trees [Picea abies (L.) Karst.] were exposed to ambient (AMB) or ambient plus 350 mu mol CO2 mol(-1) (EL) for 4 years (except winters), using the branch bag technique (BB). The trees were growing on plots with low (control) and high (irrigated-fertilised) availability of soil nutrients. The seasonal variation in foliar macronutrients and non-structural carbohydrates in current and 1-year-old shoots was monitored throughout the treatment period. When the branches were harvested at the end of treatment, macronutrients were analysed in five age classes of foliage. The concentration of all elements, except magnesium, generally increased in AMB, i.e. a 'bag effect', but decreased as an effect of EL, i.e. a 'CO2 effect'. At the final harvest K, P, N and S were reduced in young needles by EL, whereas Mg was reduced in older needles on both plots. A change in needle morphology by EL possibly caused a dilution effect in irrigated-fertilised needles, but not in control needles. Reductions in K and Mg are suggested to be an effect of increased phloem transport from the branch, in consequence of higher rates of carbon fixation in EL. Foliage in BBs had higher concentration of Ca, but there was no significant effect of the EL-treatment, indicating that elevated CO2 had no effect on stomatal conductance. Quinic acid concentration decreased, but shikimic acid concentration increased in BBs, independently of CO2 treatment. Concentrations of starch and sugars increased in the EL- treatment, but pinitol decreased.

KEYWORDS: ELEVATED ATMOSPHERIC CO2, GROWTH, LEAF ANATOMY, LEAVES, NEEDLES, PLANTS, RESPONSES, SCOTS PINE, STOMATAL CONDUCTANCE, TREES

2004

Roberntz, P., and J. Stockfors. 1998. Effects of elevated CO2 concentration and nutrition on net photosynthesis, stomatal conductance and needle respiration of field-grown Norway spruce trees. *Tree Physiology 18(4):233-241.*

To study the effects of elevated CO2 on gas exchange, nonstructural carbohydrate and nutrient concentrations in current-year folia,ae of 30-year-old Norway spruce (Picea abies (L.) Karst.) trees, branches were enclosed in ventilated, transparent plastic bags and flushed with ambient air (mean 370 mu mol CO2 mol(-1); control) or ambient air + 340 mu mol CO2 mol(-1) (elevated CO2) during two growing seasons. One branch bag was installed on each of 24 selected trees From control and fertilized plots. To reduce the effect of variation among trees, results from each treated branch were compared with those from a control branch on the same whorl of the same tree. Elevated CO2 increased rates of light-saturated photosynthesis on average by 55% when measured at the treatment CO2 concentration. The increase was larger in shoots with high needle nitrogen concentrations than in shoots with low needle nitrogen concentrations. However, shoots grown in elevated CO2 showed a decrease in photosynthetic capacity compared with shoots grown in ambient CO2. When measured at the internal CO2 concentration of 200 mu mol CO2 mol(-1), photosynthetic rates of branches in the elevated CO2 treatments were reduced by 8 to 32%. The elevated CO2 treatment caused a 9 to 20% reduction in carboxylation efficiency and an 18% increase in respiration rates. In response to elevated CO2, starch, fructose and glucose concentrations in the needles increased on average 33%, whereas concentrations of potassium, nitrogen, phosphorus, magnesium and boron decreased. Needle nitrogen concentrations explained 50-60% of the variation in photosynthesis and CO2 acclimation was greater at low nitrogen concentrations than at high nitrogen concentrations. We conclude that the enhanced photosynthetic rates found in shoots exposed to elevated CO2 increased carbohydrate concentrations, which may have a negative feedback on the photosynthetic apparatus and stimulate cyanide-resistant respiration. We also infer that the decrease in nutrient concentrations of needles exposed to elevated CO2 was the result of retranslocation of nutrients to other parts of the branch or tree.

KEYWORDS: ACCLIMATION, ATMOSPHERIC CO2, ENRICHMENT, GAS-EXCHANGE, LEAVES, NITROGEN, PICEA, PINE, PLANTS, RISING CO2

2005

Roberts, S.W., W.C. Oechel, P.J. Bryant, S.J. Hastings, J. Major, and V. Nosov. 1998. A field fumigation system for elevated carbon dioxide exposure in chaparral shrubs. *Functional Ecology 12(4):708-719.*

1. Modifications and improvements in the hardware and software of a free-air CO2 enrichment (FACE) system are described. The modifications were undertaken to minimize the amount of structure required and to improve software control of CO2 set points. 2. A new low-cost CO2 flow controller which provides increased reliability is described. 3, Analysis of system performance during a 79-day evaluation period of operation (13 h day(-1)) showed that for 1 min averages, the system is capable of maintaining a 550 p.p.m. +/- 10% CO2 set point during 78% of the operating time and a 550 p.p.m. +/- 20% set point during 95% of the operating time. Ten-minute averages were within +/- 10% and 20% during 87% and 96% of the operating time, respectively. 4, Continuous measurements of the spatial variation in CO2 concentration inside the FACE ring over an 18- day period showed that of the total 16-m diameter treatment area, the central 11-m diameter portion remains within the 550 p.p.m. +/- 10% set point. 5, Daily course gas-exchange measurements in matched individuals of the chaparral shrub Adenostoma fasciculatum just prior to and following a 6-week fumigation period at 550 p.p.m. CO2 in the FACE treatment ring showed the FACE plants with reduced photosynthetic rates and higher (less stressful) water potentials compared with control A. fasciculatum plants measured at the same times and conditions, indicating the responsiveness of this species to elevated CO2 conditions.

KEYWORDS: CO2, DESIGN

2006

Robertson, E.J., and R.M. Leech. 1995. Significant changes in cell and chloroplast development in young wheat leaves (triticum-aestivum CV hereward) grown in elevated co2. *Plant Physiology 107(1):63-71.*

Cell and chloroplast development were characterized in young Triticum aestivum cv Hereward leaves grown at ambient (350 mu L L(-1)) or at elevated (650 mu L L(-1)) CO2. In elevated CO2, cell and chloroplast expansion was accelerated by 10 and 25%, respectively, in the first leaf of 7-d-old wheat plants without disruption to the leaf developmental pattern. Elevated CO2 did not affect the number of chloroplasts in relation to mesophyll cell size or the linear relationship between chloroplast number or size and mesophyll cell size. No major changes in leaf anatomy or in chloroplast ultrastructure were detected as a result of growth in elevated CO2, but there was a marked reduction in starch accumulation. In leaf sections fluorescently tagged antisera were used to visualize and quantitate the amount of cytochrome f, the alpha- and beta-subunits of the coupling factor 1 in ATP synthase, D1 protein of the photosystem II reaction center, the 33-kD protein of the extrinsic oxygen-evolving complex, subunit II of photosystem I, and ribulose-1,5-

bisphosphate carboxylase/oxygenase. A significant finding was that in 10 to 20% of the mesophyll cells grown in elevated CO2 the 33-kD protein of the extrinsic oxygen-evolving complex of photosystem II and cytochrome f were deficient by 75%, but the other proteins accumulated normally.

KEYWORDS: ACCLIMATION, ATMOSPHERIC CO2, CARBON DIOXIDE, CROP RESPONSES, ENRICHMENT, LEAF, LIGHT, PHOTOSYNTHESIS, PLANTS, PROTEIN

2007

Robertson, E.J., M. Williams, J.L. Harwood, J.G. Lindsay, C.J. Leaver, and R.M. Leech. 1995. Mitochondria increase 3-fold and mitochondrial proteins and lipid change dramatically in postmeristematic cells in young wheat leaves grown in elevated co2. *Plant Physiology 108(2):469-474.*

A dramatic stimulation in mitochondrial biogenesis during the very early stages of leaf development was observed in young wheat plants (Triticum aestivum cv Hereward) grown in elevated CO2 (650 mu L L(-1)). An almost 3-fold increase in the number of mitochondria was observed in the very young leaf cells at the base of the first leaf of a 7-d-old wheat plant. In the same cells large increases in the accumulation of a mitochondrial chaperonin protein and the mitochondrial 2-oxoglutarate dehydrogenase complex and pyruvate dehydrogenase complex were detected by immunolabeling. Furthermore, the basal segment also shows a large increase in the rate of radiolabeling of diphosphatidylglycerol, a lipid confined to the inner mitochondrial membrane. This dramatic response in very young leaf cells to elevated CO2 suggests that the numerous documented positive effects of elevated CO2 on wheat leaf development are initiated as early as 12 h postmitosis.

KEYWORDS: CARBON DIOXIDE, ENRICHMENT, LOCALIZATION, PHOTOSYNTHESIS, RESPIRATION

2008

Robertson, G.P. 1999. Effect on the biosphere of elevated atmospheric CO2. *Science 285(5435):1852.*

2009

Robinson, C.H., A. Michelsen, J.A. Lee, S.J. Whitehead, T.V. Callaghan, M.C. Press, and S. Jonasson. 1997. Elevated atmospheric CO2 affects decomposition of Festuca vivipara (L) Sm litter and roots in experiments simulating environmental change in two contrasting arctic ecosystems. *Global Change Biology 3(1):37-49.*

Mass loss, together with nitrogen and carbon loss, from above- ground material and roots of Festuca vivipara were followed for 13 months in a high Arctic polar semidesert and a low Arctic tree-line dwarf shrub heath. Festuca vivipara for the study was obtained from plants cultivated at two different CO2 concentrations (350 and 500 mu L L(-1)) in controlled environment chambers in the UK. Each of the four resource types (shoots or roots from plants grown in elevated or ambient CO2 concentrations) was subsequently placed in an experiment simulating aspects of environmental change in each Arctic ecosystem. Air, litter and soil temperatures were increased using open-topped polythene tents at both sites, and a 58% increase in summer precipitation was simulated at the high Arctic site. Mass loss was greatest at the low Arctic site, and from the shoot material, rather than the roots. Shoots grown under an elevated CO2 concentration decomposed more slowly at the high Arctic site, and more quickly at the low Arctic one, than shoots grown at ambient CO2. After 13 months, greater amounts of C and N remained in above-ground litter from plants grown under elevated, rather than ambient, CO2 at the polar semi-desert site, although lower amounts of C remained in elevated CO2 litter at the low Arctic ecosystem. In the high Arctic, roots grown in the 500 mu L L(-1) CO2 concentration decomposed significantly more slowly than below-ground material derived from the ambient CO2 chambers. Elevated CO2 concentrations significantly increased the initial C:N ratio, % soluble carbohydrates and alpha-cellulose content, and significantly decreased the initial N content, of the above- ground material compared to that derived from the ambient treatment. Initially, the C:N ratio and percentage N were similar in both sets of roots derived from the two different CO2 treatments, but soluble carbohydrate and or-cellulose concentrations were higher, and percentage lignin lower, in the elevated CO2 treatments. The tent treatments significantly retarded shoot decomposition in both ecosystems, probably because of lower litter bag moisture contents, although the additional precipitation treatment had no effect on mass loss from the above-ground material. The results suggest that neither additional summer precipitation (up to 58%), nor soil temperature increase of 1 degrees C, which may occur by the end of the next century as an effect of a predicted 4 degrees C rise in air temperature, had an appreciable effect on root decomposition in the short term in a high Arctic soil. However, at the low Arctic site, greater root decomposition, and a lower pool of root N remaining, were observed where soil temperature was increased by 2 degrees C in response to a 4 degrees C rise in air temperature. These results suggest that decomposition below-ground in this ecosystem would increase as an effect of predicted climate change. These data also show that there is a difference in the initial results of decomposition processes between the two Arctic ecosystems in response to simulated environmental change.

KEYWORDS: CARBON DIOXIDE, CLIMATE CHANGE, FOREST, GRASS, LEAF LITTER, MINERALIZATION, NITROGEN, QUALITY, SOILS, TUNDRA

2010

Robinson, D., and J.P. Conroy. 1999. A possible plant-mediated feedback between elevated CO2, denitrification and the enhanced greenhouse effect. *Soil Biology and Biochemistry 31(1):43-53.*

Natural abundances (delta) of N-15 were used to detect effects of elevated atmospheric CO2 concentration ([CO2]) and soil wetness on soil N transformations in the presence or absence of plants. An elevated [CO2] of 1000 mu l l(-1) reduced water use by the perennial C-4 grass Panicum coloratum and stimulated root and whole-plant growth. Soil remained wetter between infrequent irrigations than in soil supporting P. coloratum grown in an ambient [CO2] (350 mu l l(-1)). The delta(15)N value of soil nitrate increased from -2.4 to + 9.6 parts per thousand as nitrate was depleted from the soil, but remained unchanged in unplanted soil. The change in delta(15)N of soil nitrate was greatest in frequently watered soil regardless of [CO2], and in infrequently watered soil only in elevated [CO2]. It was least in the infrequently watered, ambient [CO2] treatment. Isotope mass balances and N-15/N-14 fractionation theory identified denitrification as the most probable cause of this effect, through the effect of elevated [CO2] on soil wetness. Nitrification, nitrogen assimilation, leaching or ammonia volatilisation were unlikely causes. The data suggest a positive, plant-induced effect of elevated atmospheric [CO2] on denitrification. The possibility exists, therefore, for a positive feedback between elevated atmospheric [CO2], a greater soil-to-atmosphere N2O flux and an exacerbation of the enhanced greenhouse effect.

KEYWORDS: ATMOSPHERIC CO2, CARBON-DIOXIDE ENRICHMENT, GRASSLAND, ISOTOPE FRACTIONATION, N-15, NATURAL ABUNDANCE, NITRIFICATION, NITROGEN, SOIL, WATER-USE

2011

Robinson, M.F., J. Heath, and T.A. Mansfield. 1998. Disturbances in stomatal behaviour caused by air pollutants. *Journal of Experimental Botany 49:461-469.*

Many atmospheric pollutants, even when present at relatively low concentrations, may interfere with the control of stomatal aperture, and they thus have the potential to upset the water balance of the leaf or the whole plant. Although at high concentrations pollutants such as SO2 and O-3 usually cause stomatal closure, at low concentrations stomatal conductance is often increased. As well as creating a risk of loss of control of water relations, this is likely to increase the dose of the pollutant entering the mesophyll. It is, however, difficult to generalize about the nature of the physiological disturbances caused by pollutants because of variation in the responses between plants. In some cases the effects may be peculiar to one, or just a few, species. Two mechanisms underlying the interference with stomatal control have recently been identified, one involving O-3 and the other CO2. In Aster tripolium (sea aster) stomata in detached epidermal strips close as the external Na+ concentration is increased, and it has been proposed that this phenomenon is involved in the regulation of salt loading of shoot tissues. Ozone has been shown to have the capacity to interfere with Na+-induced stomatal closure, and the possibility that it therefore disrupts an aspect of salinity tolerance in this species is worthy of further research. Elevated CO2, on the other hand, has been found to interfere with the control of water relations of beech (Fagus sylvatica): for a given degree of drought, stomatal conductance and rates of soil water depletion were significantly higher in elevated CO2 than in ambient air. It is normally assumed that atmospheric CO2-enrichment will lead to increased plant productivity and improved water economy, while also providing some protection against other atmospheric pollutants through partial stomatal closure. However, the response of beech indicates that in some species there may also be detrimental effects of CO2-enrichment on plant-water relations.

KEYWORDS: ABIES L KARST, ABSCISIC- ACID, ASTER-TRIPOLIUM L, CARBON DIOXIDE, CYTOSOLIC-FREE CALCIUM, GUARD-CELLS, PLANTAGO-MAJOR L, PLASMA-MEMBRANE, SULFUR-DIOXIDE, VICIA-FABA L

2012

Rochefort, L., and F.A. Bazzaz. 1992. Growth-response to elevated CO2 in seedlings of 4 cooccurring birch species. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 22(11):1583-1587.*

Seedlings of four birch species were examined to evaluate the presence and extent of phylogenetic constraints on the response of species to global CO2 change. The species differ in their habitat preferences and their successional status. Seedlings were grown for 3 months at near ambient (380 muL L-1) and double (690 muL L-1) CO2 concentrations in glasshouses. We found the following: (i) yellow birch (Betula alleghaniensis Britton) was the only species whose survival differed among CO2 treatments. Survival was slightly increased by elevated CO2. (ii) All growth parameters considered in all four species were significantly stimulated by enriched CO2 Conditions, but the magnitude of response was different among species. The most shade-intolerant, fast-growing species (grey birch; Betula populifolia Marsh.) took greater advantage of the elevated CO2 resource than the more shade-tolerant, later successional species (e.g., yellow birch). (iii) Patterns of allocation, shoot architecture, and leaf nitrogen content were affected differently by CO2 concentrations for the different species. (iv) The presence and identity of a neighbor did not influence the magnitude or pattern of response to CO2 in birches of a given community. Our results suggest that congeneric species might be more similar in their response to global CO2 in comparison to unrelated species of the same ecosystem that had been studied by others, despite the fact that these closely related birch species differ in their habitat preferences and successional status.

KEYWORDS: ENRICHMENT, FOREST, LIQUIDAMBAR-STYRACIFLUA, NITROGEN, PINUS-TAEDA SEEDLINGS, PLANT, TREES

2013

Roden, J.S., and M.C. Ball. 1996. The effect of elevated [CO2] on growth and photosynthesis of two eucalyptus species exposed to high temperatures and water deficits. *Plant Physiology 111(3):909-919.*

Two species of eucalyptus (Eucalyptus macrorhyncha and Eucalyptus rossii) were grown for 8 weeks in either ambient (350 mu L L(-1)) or elevated (700 mu L L(-1)) CO2 concentrations, either well watered or without water additions, and subjected to a daily, 3-h high-temperature (45 degrees C, maximum) and high-light (1250 mu mol photons m(-2) s(-1), maximum) stress period. Water-stressed seedlings of E. macrorhyncha had higher leaf water potentials when grown in elevated [CO2]. Growth analysis indicated that increased [CO2] may allow eucalyptus species to perform better during conditions of low soil moisture. A down-regulation of photosynthetic capacity was observed for seedlings grown in elevated [CO2] when well watered but not when water stressed. Well-watered seedlings grown in elevated [CO2] had lower quantum efficiencies as measured by chlorophyll fluorescence (the ratio of variable to maximal chlorophyll fluorescence [F- v/F-m]) than seedlings grown in ambient [CO2] during the high- temperature stress period. However, no significant differences in F-v/F-m were observed between CO2 treatments when water was withheld. The reductions in dark-adapted F-v/F-m for plants grown in elevated [CO2] were not well correlated with increased xanthophyll cycle photoprotection. However, reductions in the F-v/F-m were correlated with increased levels of nonstructural carbohydrates. The reduction in quantum efficiencies for plants grown in elevated [CO2] is discussed in the context of feedback inhibition of electron transport associated with starch accumulation and variation in sink strength.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, CHLOROPHYLL FLUORESCENCE, DROUGHT, ELECTRON-TRANSPORT, LEAVES, LIGHT, PHOTOSYSTEM, SEEDLINGS, STRESS

2014

Roden, J.S., and M.C. Ball. 1996. Growth and photosynthesis of two eucalypt species during high temperature stress under ambient and elevated [CO2]. *Global Change Biology 2(2):115-128.*

Two species of eucalypt (Eucalyptus macrorhyncha and E. rossii) were grown under conditions of high temperatures (45 degrees C, maximum) and high light (1500 mu mol m(-2) s(-1), maximum) at either ambient (350 mu L L(-1)) or elevated (700 mu L L(-1)) CO2 concentrations for 8 weeks. The growth enhancement, in terms of total dry weight, was 41% and 103% for E. macrorhyncha and E. rossii, respectively, when grown in elevated [CO2]. A reduction in specific leaf area and increased concentrations of non-structural carbohydrates were observed for leaves grown in elevated [CO2]. Plants grown in elevated [CO2] had an overall increase in photosynthetic CO2 assimilation rate of 27%; however, when measured at the same CO2 concentration a down- regulation of photosynthesis was evident especially for E. macrorhyncha. During the midday period when temperatures and irradiances were maximal, photosynthetic efficiency as measured by chlorophyll fluorescence (F-v/F-m) was lower in E. macrorhyncha than in E. rossii. Furthermore, F-v/F-m was lower in leaves of E. macrorhyncha grown under elevated than under ambient [CO]. These reductions in F-v/F-m were accompanied by increases in both photochemical (q(p)) and nonphotochemical quenching (q(N) and NPQ), and by increases in the concentrations of xanthophyll cycle pigments with an increased

proportion of the total xanthophyll cycle pool comprising of antheraxanthin and zeaxanthin, Thus, increased atmospheric [CO2] may enhance photoinhibition when environmental stresses such as high temperatures limit the capacity of a plant to respond with growth to elevated [CO2].

KEYWORDS: CARBON DIOXIDE, CHLOROPHYLL FLUORESCENCE, COTTON PLANTS, ELECTRON-TRANSPORT, LIGHT, MECHANISM, PHOTOINHIBITION, QUANTUM YIELD, RESPONSES, SEEDLINGS

2015

Roden, J.S., J.J.G. Egerton, and M.C. Ball. 1999. Effect of elevated [CO2] on photosynthesis and growth of snow gum (Eucalyptus pauciflora) seedlings during winter and spring. *Australian Journal of Plant Physiology 26(1):37-46.*

Snow gum (Eucalyptus pauciflora Sieb. ex Spreng.) seedlings were grown from autumn through spring in open top chambers located in a pasture naturally subject to freezing temperatures in either ambient or elevated (350 mu L L-1 above ambient) CO2 concentrations. Sustained reduction in quantum efficiency, as measured by chlorophyll fluorescence (F-v/F-m), in over- wintering leaves may be related to seasonal down-regulation of photosynthesis, combined with cumulative effects of freeze- induced damage to the photosynthetic apparatus, with the effect being greater in leaves grown under elevated [CO2]. Down-regulation of photosynthesis apparently occurred in response to seasonal limitations to growth which were not overcome by elevation of [CO2] despite temperatures being favorable for photosynthesis during most of the photoperiod. Elevated [CO2] had no effect on growth of over-wintering seedlings, but enhanced growth in spring when minimum temperatures rose consistently above freezing. As there were no effects of elevated [CO2] on allocation, the stimulation of growth in spring was attributable to increase in net assimilation rates. Thus seasonal differences in photoinhibition were consistent with seasonal differences in the capacity for growth, with plants grown under elevated [CO2] having to dissipate more excess excitation energy over-winter.

KEYWORDS: CHLOROPHYLL FLUORESCENCE, CLIMATE, COLD-INDUCED PHOTOINHIBITION, ELECTRON-TRANSPORT, LEAVES, LOW-TEMPERATURE, PERFORMANCE, QUANTUM YIELD, SCOTS PINE, WATER-STRESS

2016

Roden, J.S., D.J. Wiggins, and M.C. Ball. 1997. Photosynthesis and growth of two rain forest species in simulated gaps under elevated CO2. *Ecology 78(2):385-393.*

Two species common to the temperate rain forests of New South Wales, Australia (Doryphora sassafras and Acmena smithii) were grown for 2 wk in either ambient (350 mu L/L) or elevated (700 mu L/L) CO2 concentrations and low light (30 mu mol photons . m(-2). s(-1)) after which the seedlings were exposed for over 9 wk to a midday 2-h highlight period (1250 mu mol photons . m(- 2). s(-1), maximum) to simulate a tree fall gap. For both species, plants grown in elevated CO2 had greater biomass than plants grown in ambient CO2. However, relative increases in biomass were greater in Acmena, which is an early-successional species, than Doryphora, which is a late-successional species. Doryphora sassafras also had greater reductions in photosynthetic efficiency, as measured by chlorophyll fluorescence techniques (F-v/F-m) upon exposure to the high- light treatment than Acmena. Recovery in quantum efficiencies over time was observed for Doryphora, implying physiological acclimation to the new light environment. Plants grown in elevated CO2 had lower values of F-v/F-m than plants grown in ambient CO2, but these differences between CO2 treatments were only significant for the late-successional Doryphora. Although exposure to the simulated tree fall gap dramatically increased the conversion of pigments of the xanthophyll cycle, as well as increased the total pool size of xanthophyll cycle pigments relative to total chlorophyll concentration, there were no differences in either parameter between CO2 treatments. Leaves of Doryphora and those seedlings grown in elevated CO2 had greater starch concentrations than Acmena and those seedlings grown in ambient CO2, respectively. The reduction in quantum efficiencies for plants grown in elevated CO2 and exposed to a simulated tree fall gap is discussed in the context of the importance of gap phase regeneration for species in rain forest ecosystems and the potential effects of global change on those processes.

KEYWORDS: ACCLIMATION, ALOCASIA-MACRORRHIZA, DIVERSITY, ELECTRON-TRANSPORT, LIGHT, PHOTOINHIBITION, RESPONSES, SEEDLINGS, TOLERANT, TREES

2017

Roderick, M.L., S.L. Berry, and I.R. Noble. 1999. The relationship between leaf composition and morphology at elevated CO2 concentrations. *New Phytologist 143(1):63-72.*

The composition and morphology of leaves exposed to elevated [CO2] usually change so that the leaf nitrogen (N) per unit dry mass decreases and the leaf dry mass per unit area increases. However, at ambient [CO2], leaves with a high leaf dry mass per unit area usually have low leaf hi per unit dry mass. Whether the changes in leaf properties induced by elevated [CO2] follow the same overall pattern as that at ambient [CO2] has not previously been addressed. Here we address this issue by using leaf measurements made at ambient [CO2] to develop an empirical model of the composition and morphology of leaves. Predictions from that model are then compared with a global database of leaf measurements made at ambient [CO2]. Those predictions are also compared with measurements showing the impact of elevated [CO2]. In the empirical model both the leaf dry mass and liquid mass per unit area are positively correlated with leaf thickness, whereas the mass of C per unit dry mass and the mass of N per unit liquid mass are constant. Consequently, both the N:C ratio and the surface area:volume ratio of leaves are positively correlated with the liquid content. Predictions from that model were consistent with measurements of leaf properties made at ambient [CO2] from around the world. The changes induced by elevated [CO2] follow the same overall trajectory. It is concluded that elevated [CO2] enhances the rate at which dry matter is accumulated but the overall trajectory of leaf development is conserved.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, GRADIENT, GROWTH, INSECT HERBIVORY, LEAVES, NITROGEN, PHOTOSYNTHETIC CAPACITY, RAIN-FOREST, RESPONSES

2018

Rodriguez, D., M. Van Oijen, and A.H.M.C. Schapendonk. 1999. LINGRA-CC: a sink-source model to simulate the impact of climate change and management on grassland productivity. *New Phytologist 144(2):359-368.*

A simulation model for the prediction of grassland (Lolium perenne) productivity under conditions of climate change is described and validated for grass growing in the Wageningen Rhizolab, Wageningen, The Netherlands. In this work the model was used to study the impact of different management strategies on the productivity of grassland under present and increased atmospheric CO2 concentrations. In LINGRA-CC simulated key processes are light utilization, leaf formation, leaf elongation, tillering and carbon partitioning. The daily growth rate is determined by the minimum of a sink and a source term. As in a previous model (LINGRA), the potential growth of the sink depends on the mean daily temperature, and can be modified by the effects of the availability of assimilates on tillering. The growth of roots is calculated

from the amount of carbohydrates the shoot is unable to utilize when the number or activity of the sinks is small (overflow hypothesis). The main difference between LINGRA and LINGRA-CC is the way the source of assimilates for growth is calculated. Assimilate production depends on intercepted radiation, and a photosynthetic light- use efficiency (LUE) calculated as a function of CO2, temperature, light intensity and the Rubisco concentration of upper leaves. Other differences are that in LINGRA-CC, the specific shoot area for new growth depends on the level of reserves. Data from two independent experiments with L, perenne swards, grown in enclosures at two levels of CO2 during 1994 and 1995, were used to calibrate and validate the model, respectively. The model predicted well the observed amounts of harvested biomass, and the dynamics of the leaf area index, tiller number and specific shoot area. LINGRA-CC was used to stud? the effects of different combinations of cutting interval and cutting height on biomass production, at ambient (350 mu mol mol(-1) CO2) and double (700 mu mol mol(-1) CO2) CO2 conditions. Under both ambient and doubled CO2, maximum biomass was produced with cuttings of leaf area index >1, and at cutting intervals of 20 and 17 d for ambient and increased CO2 environments, respectively. Under high CO2 conditions the curling interval for maximum yield was 15% shorter than at ambient CO2. However, the gain in harvested biomass obtained by reducing the cutting interval by 3 d under high CO2 conditions was negligible.

KEYWORDS: ELEVATED CO2, GROWTH, INCREASED CO2 CONCENTRATION, LOLIUM-PERENNE, PHOTOSYNTHESIS, PRAIRIE GRASS, RYEGRASS, TEMPERATURE, USE EFFICIENCY, WHEAT

2019

Rogers, A., B.U. Fischer, J. Bryant, M. Frehner, H. Blum, C.A. Raines, and S.P. Long. 1998. Acclimation of photosynthesis to elevated CO2 under low- nitrogen nutrition is affected by the capacity for assimilate utilization. Perennial ryegrass under free-air CO2 enrichment. *Plant Physiology 118(2):683-689.*

Acclimation of photosynthesis to elevated CO2 has previously been shown to be more pronounced when N supply is poor. Is this a direct effect of N or an indirect effect of N by limiting the development of sinks for photoassimilate? This question was tested by growing a perennial ryegrass (Lolium perenne) in the field under elevated (60 Pa) and current (36 Pa) partial pressures of CO2 (pCO2) at low and high levels of N fertilization. Cutting of this herbage crop at 4- to 8-week intervals removed about 80% of the canopy, therefore decreasing the ratio of photosynthetic area to sinks for photoassimilate. Leaf photosynthesis, in vivo carboxylation capacity, carbohydrate, N, ribulose-1,5-bisphosphate carboxylase/oxygenase, sedoheptulose-l,7-bisphosphatase, and chloroplastic fructose-1,6-bisphosphatase levels were determined for mature lamina during two consecutive summers. just before the cut, when the canopy was relatively large, growth at elevated pCO(2) and low N resulted in significant decreases in carboxylation capacity and the amount of ribulose- 1,5-bisphosphate carboxylase/oxygenase protein. In high N there were no significant decreases in carboxylation capacity or proteins, but chloroplastic fructose-1,6-bisphosphatase protein levels increased significantly. Elevated pCO(2) resulted in a marked and significant increase in leaf carbohydrate content at low N, but had no effect at high N. This acclimation at low N was absent after the harvest, when the canopy size was small. These results suggest that acclimation under low N is caused by limitation of sink development rather than being a direct effect of N supply on photosynthesis.

KEYWORDS: ACCUMULATION, CARBON DIOXIDE, GAS-EXCHANGE, GROWTH, LEAVES, PLANTS, RISING ATMOSPHERIC CO2, SOURCE-SINK RELATIONS, TRANSCRIPT LEVELS, TRIFOLIUM-REPENS L

2020

Rogers, G.S., P.W. Gras, I.L. Batey, P.J. Milham, L. Payne, and J.P. Conroy. 1998. The influence of atmospheric CO2 concentration on the protein, starch and mixing properties of wheat flour. *Australian Journal of Plant Physiology 25(3):387-393.*

Wheat (Triticum aestivum L.) cultivars Hartog and Rosella were grown at CO2 concentrations of 280 mu L L-1 (representing the pre-industrial CO2 concentration), 350 mu L L-1 (ambient) and 900 mu L L-1 tan extreme projection of atmospheric CO2 concentration). The plants were grown in naturally lit glasshouses in 7 L pots containing soil to which basal nutrients had been added and the pH adjusted to 6.5, Hartog yielded 2.4 g of grain per plant when grown at 280 mu L CO2 L- 1. This yield was increased by 38% and 75% at CO2 concentrations of 350 mu L L-1 and 900 mu L L-1 respectively. These changes were due to increases in both grain number and individual grain weight as the level of CO2 was raised. The yield of Rosella was unaffected by altering the CO2 concentration. Increasing the CO2 concentration reduced grain protein concentration of cv. Hartog from 17.4% at 280 mu L CO2 L-1 to 16.5% and 16% at CO2 concentrations of 350 mu L L-1 and 900 mu L L-1 respectively. The grain protein concentration of cv. Rosella was reduced from 10.7% to 10.2% by increasing the CO2 concentration from 280 mu L L-1 to 350 mu L L-1; however, an additional increase in the CO2 concentration to 900 mu L L-1 had no effect on grain protein concentration. In Hartog flour, the highest proportion of polymeric protein in the flour (7.7%) occurred at 280 mu L CO2 L-1. This was reduced to 6.3% at 350 mu L CO2 L-1 but then increased again to 7.0% at 900 mu L CO2 L-1. These changes in concentration of polymeric protein were correlated (r(2)=0.58) with changes in mixing properties, The mixing time required to produce optimum dough strength was greatest at 900 mu L CO2 L-1 (181 s), then 141 s and 151 s at 350 mu L CO2 L-1 and 280 mu L CO2 L-1 respectively. These changes in mixing time could not be explained by changes in grain protein concentration. The proportion of 'B' starch granules (<10 mu m diameter) increased from 25% of total weight of starch at 280 mu L CO2 L-1 to 30% at CO2 concentrations 350 and 900 mu L L-1. There were generally no effects of CO2 concentration on dough mixing properties or starch granule size distribution for Rosella.

KEYWORDS: CARBON DIOXIDE, ELEVATED CO2, GENOTYPES, GRAIN QUALITY, NITROGEN, NUTRITION, STRESS, TEMPERATURE, WINTER-WHEAT, YIELD

2021

Rogers, G.S., P.J. Milham, M. Gillings, and J.P. Conroy. 1996. Sink strength may be the key to growth and nitrogen responses in N-deficient wheat at elevated CO2. *Australian Journal of Plant Physiology 23(3):253-264.*

The influence of elevated CO2 (350, 550 and 900 mu L L(-1)) and N supplies ranging from deficient to excess (0-133 mg N kg(-1) soil week(-1)) on the leaf N concentration and shoot growth of wheat (Triticum aestivum L.), cultivar Hartog, was investigated. Shoot growth was 30 % greater at 550 mu L L(-1) compared to ambient CO2 at all levels of N supply. When the CO2 concentration was increased to 900 mu L L(-1), there was no increase in shoot growth at low N supply but it more than doubled at high N supply (67 mg N kg(-1) soil week(-1)). Growth effects were closely matched by changes in sink development, suggesting that sink strength, mediated through N supply controlled the shoot growth response to elevated CO2 The shoot N concentration was lower at each level of CO2 enrichment and the greatest effect (30% reduction) occurred at 900 mu L CO2 L(-1), 33 mg N kg(-1) soil week(-1). The effect of high CO2 on shoot N concentration diminished as N supply increased and, at the highest N addition rate, there was only a 7% reduction. Changes in foliar N concentration due to CO2 enrichment were closely correlated with lower soluble protein concentration, accounting for 58 % of the total leaf N reduction. Ribulose- 1,5-

bisphosphate carboxylase/oxygenase (Rubisco) levels we:re also reduced at high CO2 and N was allocated away from Rubisco and into other soluble proteins at high CO2 when N supply was low. Nonstructural carbohydrate concentration (dry weight basis) was greatest at 900 mu L CO2 L(-1) and low N supply and may have reduced Rubisco concentration via a feed-back response. Critical foliar N concentrations (N concentration at 90 % of maximum shoot growth) were reduced from 43 mg g(-1) at ambient CO2 to 39 and 38 mg g(-1) at 550 and 900 mu L CO2 L(- 1), respectively. Elevated CO2, at N supplies of 0-17 mg N kg(- 1) soil week(-1), reduced flour protein concentration by 9-13 %.

KEYWORDS: CARBAMYLATION, CARBON DIOXIDE, ENRICHMENT, NUTRITION, PHOTOSYNTHESIS, PLANTS, PROTEIN, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE, STRESS, TOBACCO

2022

Rogers, G.S., P.J. Milham, M.C. Thibaud, and J.P. Conroy. 1996. Interactions between rising CO2 concentration and nitrogen supply in cotton .1. Growth and leaf nitrogen concentration. *Australian Journal of Plant Physiology 23(2):119-125.*

The influence of sink development on the response of shoot growth in cotton (Gossypium hirsutum L. cv. Siokra BT1-4) was investigated by growing plants at three levels of CO2 concentration: 350 (ambient), 550 and 900 mu L L(-1) and six levels of nitrogen (N) supply ranging from deficient to excess (0-133 mg N kg(-1) soil week(-1)). Changes in leaf N concentration were also investigated. At 59 days after sowing, there was an average 63% increase in shoot growth at 550 mu L CO2 L(-1) compared with ambient CO2-grown plants, with no significant growth increase at 900 mu L CO2 L(-1) and, this response was closely matched by sink development (flower number and stem weight). Low N supply restricted the responses of both sink development and shoot growth to high CO2. At elevated CO2, leaf N concentration was reduced by an average 27% at low to adequate N supply. The high CO2-induced reduction in leaf N concentration, however, disappeared when the N supply was increased to a high level of 133 mg N kg(-1) soil week(-1). These CO2 effects on leaf N concentration were smaller when N was expressed per unit leaf area, apparently due to a combination of the effects of elevated CO2 or high N supply reducing specific leaf area and, to an N uptake limitation at low to moderate levels of N supply. The critical foliar N concentrations (leaf N concentration at 90% of maximum shoot growth) were reduced from 42 to 38 and 36 mg g(-1) when CO2 concentrations were increased from 350 to 550 and 900 mu L L(- 1) respectively, indicating that changes in fertiliser management may be required under changing CO2 concentrations.

KEYWORDS: C-3 PLANTS, CARBOHYDRATE, CARBON, LEAVES, PHOTOSYNTHESIS, WHEAT

2023

Rogers, G.S., L. Payne, P. Milham, and J. Conroy. 1993. Nitrogen and phosphorus requirements of cotton and wheat under changing atmospheric co2 concentrations. *Plant and Soil 156:231-234.*

The influence of increasing atmospheric CO2 on shoot growth, leaf nitrogen and phosphorus concentrations and carbohydrate composition was investigated in cotton and wheat. Shoot dry weight of both species was generally higher at elevated CO2, especially at high rates of available soil N and P. Critical leaf N concentration was reduced but critical P concentration was increased in both species at high CO2.

KEYWORDS: CARBOHYDRATE, ENRICHMENT, GROWTH, METABOLISM, STRESS

2024

Rogers, H.H., and R.C. Dahlman. 1993. Crop responses to co2 enrichment. *Vegetatio 104:117-131.*

Carbon dioxide is rising in the global atmosphere, and this increase can be expected to continue into the foreseeable future. This compound is an essential input to plant life. Crop function is affected across all scales from biochemical to agro-ecosystem. An array of methods (leaf cuvettes, field chambers, free-air release systems) are available for experimental studies of CO2 effects. Carbon dioxide enrichment of the air in which crops grow usually stimulates their growth and yield. Plant structure and physiology are markedly altered. Interactions between CO2 and environmental factors that influence plants are known to occur. Implications for crop growth and yield are enormous. Strategies designed to assure future global food security must include a consideration of crop responses to elevated atmospheric CO2. Future research should include these targets: search for new insights, development of new techniques, construction of better simulation models, investigation of belowground processes, study of interactions, and the elimination of major discrepancies in the scientific knowledge base.

KEYWORDS: AGRICULTURAL PRODUCTIVITY, AIR-TEMPERATURE, CLIMATIC CHANGE, ELEVATED CARBON-DIOXIDE, INCREASING ATMOSPHERIC CO2, MINERAL NUTRITION, PLANT GROWTH, SOYBEAN CANOPY, WATER-USE EFFICIENCY, WINTER-WHEAT

2025

Rogers, H.H., C.M. Peterson, J.N. McCrimmon, and J.D. Cure. 1992. Response of plant-roots to elevated atmospheric carbon-dioxide. *Plant, Cell and Environment 15(6):749-752.*

Plant root response to atmospheric CO2 enrichment can be great. Results from this controlled environment investigation demonstrate substantial effects on root system architecture, micromorphology and physiology. The most pronounced effects were an increase in root length (110%) and root dry weight (143%). Root diameter, stele diameter, cortex width, root/shoot and root weight ratios all increased; root numbers did not increase. The long-term implications for belowground processes could be enormous.

KEYWORDS: GROWTH

2026

Rogers, H.H., S.A. Prior, and E.G. Oneill. 1992. Cotton root and rhizosphere responses to free-air co-2 enrichment. *Critical Reviews in Plant Sciences 11(2-3):251-263.*

KEYWORDS: AGRICULTURE, CARBON DIOXIDE, CO2, GROWTH, INFECTION, SOIL, WHEAT, YIELD

2027

Rogers, H.H., S.A. Prior, and G.B. Runion. 1993. Effects of elevated atmospheric co2 on soybean and sorghum root-growth. *Plant Physiology 102(1):173.*

2028

Rogers, H.H., S.A. Prior, G.B. Runion, and R.J. Mitchell. 1996. Root to shoot ratio of crops as influenced by CO2. *Plant and Soil 187(2):229-248.*

Crops of tomorrow are likely to grow under higher levels of atmospheric CO2. Fundamental crop growth processes will be affected and chief

among these is carbon allocation. The root to shoot ratio (R:S, defined as dry weight of root biomass divided by dry weight of shoot biomass) depends upon the partitioning of photosynthate which may be influenced by environmental stimuli. Exposure of plant canopies to high CO2 concentration often stimulates the growth of both shoot and root, but the question remains whether elevated atmospheric CO2 concentration will affect roots and shoots of crop plants proportionally. Since elevated CO2 can induce changes in plant structure and function, there may be differences in allocation between root and shoot, at least under some conditions. The effect of elevated atmospheric CO2 on carbon allocation has yet to be fully elucidated, especially in the context of changing resource availability, Herein we review root to shoot allocation as affected by increased concentrations of atmospheric CO2 and provide recommendations for further research. Review of the available literature shows substantial variation in R:S response for crop plants. In many cases (59.5%) R:S increased, in a very few (3.0%) remained unchanged, and in others (37.5%) decreased. The explanation for these differences probably resides in crop type, resource supply, and other experimental factors. Efforts to understand allocation under CO2 enrichment will add substantially to the global change response data base.

KEYWORDS: ATMOSPHERIC PARTIAL-PRESSURE, CARBOHYDRATE CONTENT, CARBON-DIOXIDE ENRICHMENT, DRY-MATTER, ELEVATED CO2, MECHANICAL IMPEDANCE, PHOTOSYNTHETIC ACCLIMATION, PLANT GROWTH, WATER-STRESS, YIELD RESPONSES

2029

Rogers, H.H., G.B. Runion, and S.V. Krupa. 1994. Plant-responses to atmospheric co2 enrichment with emphasis on roots and the rhizosphere. *Environmental Pollution 83(1-2):155-189.*

Empirical records provide incontestable evidence of global changes; foremost among these changes is the rising concentration of CO2 in the earth's atmosphere. Plant growth is nearly always stimulated by elevation of CO2. Photosynthesis increases, more plant biomass accumulates per unit of water consumed, and economic yield is enhanced The profitable use of supplemental CO2 over years of greenhouse practice points to the value of CO2 for plant production. Plant responses to CO2 are known to interact with other environmental factors, e.g. light, temperature, soil water, and humidity. Important stresses including drought, temperature, salinity, and air pollution have been shown to be ameliorated when CO2 levels are elevated In the agricultural context, the growing season has been shortened for some crops with the application of more CO2; less water use has generally, but not always, been observed and is under further study; experimental studies have shown that economic yield for most crops increases by about 33% for a doubling of ambient CO2 concentration. However, there are some reports of negligible or negative effects. Plant species respond differently to CO2 enrichment, therefore, clearly competitive shifts within natural communities could occur. Though of less importance in managed agro-ecosystems, competition between crops and weeds could also be altered. Tissue composition can vary as CO2 increases (e.g. higher C:N ratios) leading to changes in herbivory, but tests of crop products (consumed by man) from elevated CO2 experiments have generally not revealed significant differences in their quality. However, any CO2-induced change in plant chemical or structural make-up could lead to alterations in the plant's interaction with any number of environmental factors- physicochemical or biological. Host-pathogen relationships, defense against physical stressors, and the capacity to overcome resource shortages could be impacted by rises in CO2. Root biomass is known to increase but, with few exceptions, detailed studies of root growth and function are lacking. Potential enhancement of root growth could translate into greater rhizodeposition, which, in turn, could lead to shifts in the rhizosphere itself. Some of the direct effects of CO2 on vegetation have been reasonably well-studied, but for others work has been inadequate. Among these neglected areas are plant roots and the rhizosphere. Therefore, experiments on root and rhizosphere response in plants grown in CO2-enriched atmospheres will be reviewed and, where possible, collectively integrated To this will be added data which have recently been collected by us. Having looked at the available data base, we will offer a series of hypotheses which we consider as priority targets for future research.

KEYWORDS: CARBON-DIOXIDE ENRICHMENT, ELEVATED CO2, FIELD-GROWN SOYBEANS, KUDZU PUERARIA-LOBATA, LONG-TERM EXPOSURE, OPEN-TOP CHAMBERS, PINUS-TAEDA SEEDLINGS, SOUR ORANGE TREES, SOYBEAN GLYCINE-MAX, WATER-USE EFFICIENCY

2030

Rolland, C., V. Petitcolas, and R. Michalet. 1998. Changes in radial tree growth for Picea abies, Larix decidua, Pinus cembra and Pinus uncinata near the alpine timberline since 1750. *Trees-Structure and Function 13(1):40-53.*

Changes in radial growth of the four coniferous species growing in the French Alps near the upper treeline are investigated. Thirty-seven populations of Norway spruce [Picea abies (L.) Karat.], European larch (Larix decidua Mill.), Swiss stone pine (Pinus cembra L.) and mountain pine (Pinus uncinata Mill. ex Mirb.) were sampled by taking 1320 cores and analysing treering widths. Sites were chosen in various climatic conditions (macroclimate and aspect) and on two kinds of bedrock in order to take into account the ecological be haviour of these species. Belledonne, Moyenne-Tarentaise: Haute-Maurienne and Brianconnais areas were sampled along increasing gradients of summer aridity and winter continentality. The calculation of time series after removing the age trend brings strong evidence for an increase in radial growth during the two last centuries, but with different stages and fluctuations for each species. This growth trend is significantly enhanced since 1860 for the spruce, and since 1920 for the two pine species. Furthermore, it also appears on Larix decidua with the same pattern despite periodical growth reduction due to attacks of the larch bud moth (Zeiraphera diniana Gn.). The analysis of ring-widths at a given cambial age reveals that this enhanced phenomenon is observed especially during the tree's early years (25-75 years). The analysis of four regional climatic series, and three longer series of temperature (in farther single sites) reveals synchronous decadal fluctuations and an evident secular increase in minimum temperatures (especially in January and from July to October), that may be involved in tree-growth enhancement. Thermic amplitudes are significantly reduced during the whole growing period, what is more pronounced in Belledonne, the most oceanic region. Long term growth changes are well described by stepwise regression models, especially for the pine species. These models involved both a linear trend (CO2 concentration or N-deposition) and low frequency of Turin monthly temperatures. However, they show different patterns than those observed from response functions at a yearly scale.

KEYWORDS: CARBON DIOXIDE, CO2, FOREST, FRANCE, HIGH-ELEVATION SITES, RESPONSES, SPRUCE MODEL-ECOSYSTEMS, TEMPERATURE, TRENDS

2031

Ronen-Tarazi, M., D.J. Bonfil, D. Schatz, and A. Kaplan. 1998. Cyanobacterial mutants impaired in bicarbonate uptake isolated with the aid of an inactivation library. *Canadian Journal of Botany-Revue Canadienne De Botanique 76(6):942-948.*

An inactivation library consisting of genomic fragments ligated within a modified bluescript vector was used to isolate several new high CO2 requiring mutants of Synechococcus PCC7942. The mutants described hen were impaired in the ability to accumulate C-i internally when supplied with HCO3-. The relevant genomic regions bearing novel genes

involved in the ability to transport and to accumulate Ci within the cells and thus to grow under low-CO2 conditions are presented. Some of the mutants were also impaired in ability to adjust to an elevated pH in their medium. We show that the use of inactivation libraries enabled cloning of genes encoding membrane-located proteins; we point to mutations introduced by the single cross-recombination events resulting in the formation of some of these mutants. Possible artifacts that may result in incorrect identification of genes, the inactivation of which could have led to the observed phenotype, are discussed.

KEYWORDS: CO2 CONCENTRATING MECHANISM, INORGANIC CARBON, PCC6803, PHOTOSYNTHESIS, REGION, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, SP STRAIN PCC-7942, SUBUNIT, SYNECHOCOCCUS, TRANSPORT

2032

Ronentarazi, M., J. Liemanhurwitz, C. Gabay, M.I. Orus, and A. Kaplan. 1995. The genomic region of rbcls in synechococcus sp pcc-7942 contains genes involved in the ability to crow under low co2 concentration and in chlorophyll biosynthesis. *Plant Physiology 108(4):1461-1469.*

Several genes involved in the ability of Synechococcus sp. PCC 7942 to grow under different CO, concentrations were mapped in the genomic region of rbcLS (the operon encoding the large and small subunits of ribulose-1,5-bisphosphate carboxylase/oxygenase). Insertion of a cartridge encoding kanamycin resistance within open reading frame (ORF) 78, designated ccmJ, located 7 kb upstream of rbcLS, resulted in a kanamycin-resistant, high-CO2-requiring mutant, M3, which does not contain normal carboxysomes. ccmJ shows significant homology to csoS1 encoding a carboxysomal shell polypeptide in Thiobacillus neopolitanus. Analysis of the polypeptide pattern of a carboxysome-enriched fraction indicated several differences between the wild type and the mutant. The amount of the ribulose-1,5-bisphosphate carboxylase/oxygenase subunits was considerably smaller in the carboxysomal fraction of the mutant when compared to the wild type. On the basis of the sequence analyses, ORF286 and ORF466, located downstream of ccmJ were identified as chit and chlN, respectively, which are involved in chlorophyll biosynthesis in the dark.

KEYWORDS: ANACYSTIS-NIDULANS, CARBOXYLASE-OXYGENASE, CARBOXYSOME, CYANOBACTERIA, INORGANIC-CARBON UPTAKE, MECHANISM, MICROALGAE, PCC7942, TRANSPORT

2033

Rosenqvist, E., H. Pedersen, and C.O. Ottosen. 1996. Effects of elevated CO2 on growth and photosynthesis in dendranthema grandiflorum. *Plant Physiology 111(2):355.*

2034

Rosenthal, Y. 1998. Variations of ecosystem gas exchange in the rain forest mesocosm at Biosphere 2 in response to elevated CO2. *Global Change Biology 4(5):539-547.*

The effects of elevated CO2 on tropical ecosystems were studied in the artificial rain forest mesocosm at Biosphere 2, a large- scale and ecologically diverse experimental facility located in Oracle, Arizona. The ecosystem responses were assessed by comparing the whole-system net gas exchange (NEE) upon changing CO2 levels from 900 to 450 ppmV. The day-NEE was significantly higher in the elevated CO2 treatment. In both experiments, the NEE rates were similar to values observed in natural analogue systems. Variations in night-NEE, reflecting both soil CO2 efflux and plants respiration, covaried with temperature but showed no clear correlation with atmospheric CO2 levels. After correcting for changes in CO2 efflux we show that the rain forest net photosynthesis increased in response to increasing atmospheric CO2. The photosynthetic enhancement was expressed in higher quantum yields, maximum assimilation rates and radiation use efficiency. The results suggest that photosynthesis in large tropical trees is CO2 sensitive, at least following short exposures of days to weeks. Taken at face value, the data suggest that as a result of anthropogenic emissions of CO2, tropical rain forests may shift out of steady state, and become a carbon sink at least for short periods. However, a better understanding of the unique conditions and phenomena in Biosphere 2 is necessary before these results are broadly useful.

KEYWORDS: ACCLIMATION, CARBON DIOXIDE, MODEL

2035

Rosenthal, Y., B. Farnsworth, F.V.R. Romo, G.H. Lin, and B.D.V. Marino. 1999. High quality, continuous measurements of CO2 in Biosphere 2 to assess whole mesocosm carbon cycling. *Ecological Engineering 13(1-4):249-262.*

Accurate measurements of atmospheric CO2 concentrations are performed routinely in a variety of experimental settings including open fields and forests, leaf gas-exchange chambers, phytotrons and specialized growth chambers. However, the accurate monitoring of large scale structurally and biologically complex experimental systems, operating as materially closed systems, is not widely reported. Here we report the design elements, material specifications and other details for high precision monitoring of CO2 in Biosphere 2, a large scale ecologically diverse experimental facility located in Oracle, AZ. The results are used to illustrate how carbon balance in a temporarily isolated sub-system of the facility is used to assess carbon dynamics under different environmental conditions such as variable atmospheric CO2 levels, temperature, light, and soil moisture. The analytical system described here should be applicable for any settings in which continuous, high accuracy measurements of CO2 in a complex system are needed for quantitative research.

KEYWORDS: ACCLIMATION, ELEVATED CO2, FOREST, GAS-EXCHANGE

2036

Rosenzweig, C., and D. Hillel. 1993. Agriculture in a greenhouse world. *Research & Exploration 9(2):208-221.*

While agriculture in some temperate regions may benefit from global climate change, tropical and subtropical regions may suffer. Even where potential production will improve, the required adjustments may disrupt ecosystems and land-use patterns. Agricultural zones will shift toward high latitudes, while heat stress and increased droughts will reduce productivity in lower latitudes. On the positive side, higher CO2 may enhance photosynthesis and water-use efficiency. Future hazards include sea-level rise, insect infestation, and greater evaporation losses. Some agricultural activities augment the greenhouse effect by releasing CO2, CH4, and N2O. Understanding the potential impacts of climate change is a prerequisite to developing societal responses.

KEYWORDS: CLIMATE CHANGE

2037

Rosenzweig, C., J. Phillips, R. Goldberg, J. Carroll, and T. Hodges. 1996. Potential impacts of climate change on citrus and potato production in the US. *Agricultural Systems 52(4):455-479.*

Potential impacts of global climate change on fruit and vegetable yield

in the US were investigated through simulations of citrus and potato. Simulated treatments included combinations of three increased temperature regimes (+1.5, +2.5 and +5.0 degrees C), and estimates of the impact of three levels of atmospheric carbon dioxide (440, 530, and 600 ppm) in addition to control runs representing current climatic conditions. Adaptive planting dates of -28, -14, +14 and +28 days were included in the potato simulations for current and increased temperature regimes. Twenty-two sites were simulated for citrus yields and 12 sites for potato, using climate records from 1951 to 1980. Response surfaces were developed for all combinations of increased temperature and CO2. Results of citrus simulations without CO2-induced yield improvement indicate that production may shift slightly northward in the southern states, but yields may decline in southern Florida and Texas due to excessive heat during the winter. CO2 effects tended to counteract the decline in simulated citrus yields. Fall potato production under current management practices appears vulnerable to an increase in temperature in the northern states; increased CO2 and changes in planting date were estimated to have minimal compensating impacts on simulated potato yields.

KEYWORDS: DARK RESPIRATION, DRY-MATTER PRODUCTION, ELEVATION, GROWTH, HEAT TOLERANCE, HIGH-TEMPERATURE, SOLANUM TUBEROSUM L, SOUR ORANGE TREES, WATER DEFICIT, YIELD PERFORMANCE

2038

Rosenzweig, C., and F.N. Tubiello. 1996. Effects of changes in minimum and maximum temperature on wheat yields in the central US - A simulation study. *Agricultural and Forest Meteorology 80(2-4):215-230.*

Recent observations and general circulation models indicate that future temperature changes linked to global warming might be characterized by a marked asymmetry between daytime maxima and nighttime minima. We investigate the importance of such a pattern in determining future wheat (Triticum aestivum) yields in the Central United States by using a dynamic crop growth model, CERES-Wheat, modified to include physiological effects of temperature and CO2 on canopy photosynthesis. Simulations are run at four sites spanning a north-south transect of the Central US; four mean temperatures increases (1-4 degrees C) are applied to baseline daily climate data (1951-1980). The effects of two different scenarios of temperature change (minimum and maximum temperatures equally raised; minima increased three times as much as maxima in agreement with recent observations) are analyzed under both current (330 ppm) and elevated (550 ppm) CO2 concentrations. The main mechanisms controlling the simulated wheat responses are direct and indirect temperature effects on wheat phenological development. Negative effects of temperature on simulated wheat yields are reduced when minima increase more than maxima. Yield changes are consistently negative under temperature change and current CO2 concentration, while they range from positive to negative under temperature change and elevated CO2 concentration. Responses vary across the transect, with larger negative effects occurring at the southernmost site.

KEYWORDS: CERES, CLIMATE CHANGE, CROP RESPONSE, MODEL

2039

Ross, D.J., S. Saggar, K.R. Tate, C.W. Feltham, and P.C.D. Newton. 1996. Elevated CO2 effects on carbon and nitrogen cycling in grass/clover turves of a Psammaquent soil. *Plant and Soil 182(2):185-198.*

Effects of elevated CO2 (525 and 700 mu L L(-1)), and a control (350 mu L L(-1) CO2), on biochemical properties of a Mollic Psammaquent soil in a well-established pasture of C3 and C4 grasses and clover were investigated with continuously moist turves in growth chambers over four consecutive seasonal temperature regimes from spring to winter inclusive. After a further 'spring' period, half of the turves under 350 and 700 mu L L(-1) were subjected to 'summer' drying and were then re-wetted before a further 'autumn' period; the remaining turves were kept continuously moist throughout these additional three consecutive 'seasons'. The continuously moist turves were then pulse-labelled with C-14-CO2 to follow C pathways in the plant/soil system during 35 days. Growth rates of herbage during the first four 'seasons' averaged 4.6 g m(-2) day(-1) under 700 mu L L(-1) CO2 and were about 10% higher than under the other two treatments. Below-ground net productivity at the end of these 'seasons' averaged 465, 800 and 824 g m(-2) in the control, 525 and 700 mu L L(-1) treatments, respectively. In continuously moist soil, elevated CO2 had no overall effects on total, extractable or microbial C and N, or invertase activity, but resulted in increased CO2-C production from soil, and from added herbage during the initial stages of decomposition over 21 days; rates of root decomposition were unaffected. CO2 produced h(-1) mg(-1) microbial C was about 10% higher in the 700 mu L L(-1) CO2 treatment than in the other two treatments. Elevated CO2 had no clearly defined effects on N availability, or on the net N mineralization of added herbage. In the labelling experiment, relatively more C-14 in the plant/soil system occurred below ground under elevated CO2, with enhanced turnover of C-14 also being suggested. Drying increased levels of extractable C and organic-N, but decreased mineral-N concentrations; it had no effect on microbial C, but resulted in lowered microbial N in the control only. In soil that had been previously 'summer'-dried, CO2 production was again higher, but net N mineralization was lower, under elevated CO2 than in the control after 'autumn' pasture growth. Over the trial period of 422 days, elevated CO2 generally appears to have had a greater effect on soil C turnover than on soil C pools in this pasture ecosystem.

KEYWORDS: BIOCIDAL TREATMENTS, EXTRACTION METHOD, GRASS, LOLIUM-PERENNE, MICROBIAL BIOMASS, PASTURE TURVES, PLANTS, RHIZOSPHERE PH, SIMULATED SEASONAL-CHANGES, TEMPERATURE

2040

Ross, D.J., K.R. Tate, and P.C.D. Newton. 1995. Elevated co2 and temperature effects on soil carbon and nitrogen cycling in ryegrass/white clover turves of an endoaquept soil. *Plant and Soil 176(1):37-49.*

Effects of elevated CO2 (700 mu L L(-1)) and a control (350 mu L L(-1) CO2) on the productivity of a 3-year-old rye- grass/white clover pasture, and on soil biochemical properties, were investigated with turves of a Typic Endoaquept soil in growth chambers. Temperature treatments corresponding to average winter, spring, and summer conditions in the field were applied consecutively to all of the turves. An additional treatment, at 700 mu L L(-1) CO2 and a temperature 6 degrees C higher throughout than in the other treatments, was included. Under the same temperature conditions, overall herbage yields in the '700 mu L L(-1) CO2' treatment were ca. 7% greater than in the control at the end of the 'summer' period. Root mass (to ca 25 cm depth) in the '700 mu L L(-1) CO2' treatment was then about 50% greater than in the control, but in the '700 mu L L(- 1) CO2 + 6 degrees C' treatment it was 6% lower than in the control. Based on decomposition results, herbage from the '700 mu L L(-1) + 6 degrees C' treatment probably contained the highest proportion of readily decomposable components. Elevated CO2 had no consistent effect on soil total C and N, microbial C and N, or extractable C concentrations in any of the treatments. Under the same temperature conditions, it did, however, enhance soil respiration (CO2-C production) and invertase activity. The effects of elevated CO2 on rates of net N mineralization were less distinct, and the apparent availability of N for the sward was not affected. Under elevated CO2, soil in the higher-temperature treatment had a higher microbial C:N ratio; it also had a greater potential to degrade plant materials. Data interpretation was

complicated by soil spatial variability and the moderately high background levels of organic matter and biochemical properties that are typical of New Zealand pasture soils. More rapid cycling of C under CO2 enrichment is, nevertheless, indicated. Futher long- term experiments are required to determine the overall effect of elevated CO2 on the soil C balance.

KEYWORDS: ATMOSPHERIC CO2, BIOCIDAL TREATMENTS, CHLOROFORM, DECOMPOSITION, DIOXIDE, DIRECT EXTRACTION METHOD, FUMIGATION, MICROBIAL BIOMASS-C, MINERALIZATION, RESIDUES

2041

RossKarstens, G.S., G. Ebert, and P. Ludders. 1996. Diurnal time courses of CO2 gas exchange in closed and open gas systems for coffee (Coffea arabica L), pomegranate (Punica granatum L), citrus (Citrus limonia Osb), grape (Vitis vinifera L), and banana (Musa x paradisiaca L) in vitro plantlets under different environment conditions. *Journal of Applied Botany-Angewandte Botanik 70(3-4):155-162.*

Continuous measurements were made of CO2 gas exchange over a period of three days on ill vitro plantlets of coffee (Coffea arabica L.), pomegranate (Punica granatum L.), citrus (Citrus limonia Osb.), grape (Vitis vinifera L.), and banana (Musa x paradisiaca L.). The gas used for measurements contained CO2 concentrations of 350, 600, 1000 or 2000 mu l l(-1). Measurements in the closed system for coffee plantlets grown in medium containing different sucrose concentrations showed a strong decrease of the CO2 concentration in the cuvette atmosphere during the light period almost reaching the CO2 compensation point (70 mu l l(-1) CO2). During the dark period a continuous increase was observed. Measured in the open system diurnal time courses of in vitro pomegranate and citrus plantlets showed that CO2 assimilation rates were strongly influenced by light intensity and temperature. A positive balance of CO2 gas exchange was found for pomegranate plantlets only with light intensities beyond 100 mu mol m(-2) s(-1) photosynthetic photon flux density (PPFD). Citrus plantlets were independent of the sucrose concentration in the medium and showed a positive CO2 balance at 350 mu l l(-1) CO2 gas concentration. Banana plantlets revealed negative balances under all conditions examined.

KEYWORDS: CULTURE, ENRICHMENT, GROWTH, INVITRO, PHOTOSYNTHETIC CHARACTERISTICS, TOBACCO

2042

RossKarstens, G.S., G. Ebert, and P. Ludders. 1996. Influence of CO2 concentration, light intensity, and sucrose concentration on net photosynthesis of citrus plantlets during in vitro propagation. *Journal of Applied Botany-Angewandte Botanik 70(5-6):188-193.*

Light curves of the CO2 gas exchange of irt vitro plantlets of citrus (Citrus limonia Osb. (Rutaceae)) were measured continuously in an open system using different CO2 concentrations (350, 1000, and 2000 mu l l(-1) CO2). The plantlets were grown in media with sucrose concentrations from 0 to 5% under light intensities of 60, 100, and 260 mu mol m(- 2) l(-1). Before starting the measurements the plantlets were pretreated with 1000 mu l l(-1) CO2 for several weeks. Control plantlets were grown for the same period in gas tight vessels. CO2 concentration of the gas atmosphere inside the plant vessels had a stronger influence on CO2 gas exchange of citrus plantlets than sucrose concentration of the medium. Net photosynthesis of plantlets grown under various light intensities differed only little when using the same CO2 concentration for measurement as used for growing. After pretreatment with 1000 mu l l(-1) CO2 during growth, net photosynthesis of plantlets measured under 350 Cll l(-1) CO2 was higher compared to control plantlets.

KEYWORDS: ASPARAGUS, CARBON DIOXIDE, CULTURE, ENRICHMENT, GROWTH, INVITRO

2043

Roth, S.K., and R.L. Lindroth. 1994. Effects of co2-mediated changes in paper birch and white-pine chemistry on gypsy-moth performance. *Oecologia 98(2):133-138.*

We examined the effects of CO2-mediated changes in the foliar chemistry of paper birch (Betula papyrifera) and white pine (Pinus strobus) on performance of the gypsy moth (Lymantria dispar). Trees were grown under ambient or enriched CO2 conditions, and foliage was subjected to plant chemical assays and insect bioassays. Enriched CO2 atmospheres reduced foliar nitrogen levels and increased condensed tannin levels in birch but not in pine. Foliar carbohydrate concentrations were not markedly altered by CO2 environment. Gypsy moth performance was significantly affected by CO2 level, species, and the CO2 x species interaction. Under elevated CO2 conditions, growth was reduced for larvae fed birch, while development was prolonged for larvae fed pine. Although gypsy moths performed better overall on birch than pine, birch-fed larvae were influenced more by CO2-mediated changes in host quality.

KEYWORDS: CARBON NUTRIENT BALANCE, CHEMICAL DEFENSE, CO2, NITROGEN, PLANTS, PROTEIN, RESOURCE AVAILABILITY, TURNOVER

2044

Roth, S.K., and R.L. Lindroth. 1995. Elevated atmospheric co2 effects on phytochemistry, insect performance and insect parasitoid interactions. *Global Change Biology 1(3):173-182.*

This study was conducted to examine the effects of CO2-mediated changes in tree chemistry on the performance of the gypsy moth (Lymantria dispar L.) and the parasitoid Cotesia melanoscela (Ratz.). We used carbon-nutrient balance theory to develop hypotheses regarding changes in tree chemistry and the performance of both insects under elevated CO2. As predicted, levels of foliar nitrogen declined and concentrations of carbon-based compounds (e.g. starch and phenolics) increased under elevated CO2. Gypsy moth performance (e.g. growth, development) was altered by CO2-mediated changes in foliar chemistry, but the magnitude was small and varied across tree species. Larvae feeding on high CO2 aspen exhibited the largest reduction in performance, relative to larvae feeding on birch, oak, or maple. Parasitism by C. melanoscela significantly prolonged gypsy moth development and reduced growth rates. Overall, the effect of parasitism on gypsy moth performance did not differ between CO2 treatments. Altered gypsy moth performance on high CO2 foliage in turn affected parasitoid performance, but the response was variable: parasitoid mortality increased and adult female size declined slightly under high CO2, while development time and adult male size were unaffected. Our results suggest that CO2-induced changes in plant chemistry were buffered to the extent that effects on third trophic level interactions were weak to non-existent for the system examined in this study.

KEYWORDS: CARBON NUTRIENT BALANCE, DEFENSE, DIET, NITROGEN, PLANTS, PROTEIN, TREES

2045

Roth, S., R.L. Lindroth, J.C. Volin, and E.L. Kruger. 1998. Enriched atmospheric CO2 and defoliation: effects on tree chemistry and insect performance. *Global Change Biology 4(4):419-430.*

We examined the effects of CO2 and defoliation on tree chemistry and performance of the forest tent caterpillar, Malacosoma disstria. Quaking aspen (Populus tremuloides) and sugar maple (Acer saccharum) trees

were grown in open-top chambers under ambient or elevated concentrations of CO2. During the second year of growth, half of the trees were exposed to free-feeding forest tent caterpillars, while the remaining trees served as nondefoliated controls. Foliage was collected weekly for phytochemical analysis. Insect performance was evaluated on foliage from each of the treatments. At the sampling date coincident with insect bioassays, levels of foliar nitrogen and starch were lower and higher, respectively, in high CO2 foliage, and this trend persisted throughout the study. CO2-mediated increases in secondary compounds were observed for condensed tannins in aspen and gallotannins in maple. Defoliation reduced levels of water and nitrogen in aspen but had no effect on primary metabolites in maple. Similarly, defoliation induced accumulations of secondary compounds in aspen but not in maple. Larvae fed foliage from the enriched CO2 or defoliated treatments exhibited reduced growth and food processing efficiencies, relative to larvae on ambient CO2 or nondefoliated diets, but the patterns were host species-specific. Overall, CO2 and defoliation appeared to exert independent effects on foliar chemistry and forest tent caterpillar performance.

KEYWORDS: BIRCH, CARBON NUTRIENT BALANCE, COVARIANCE, FOLIAGE, HERBIVORE RESPONSES, INDUCTION, MOTH, NITROGEN, PHYTOCHEMISTRY, PLANTS

2046

Roth, S., E.P. McDonald, and R.L. Lindroth. 1997. Atmospheric CO2 and soil water availability: consequences for tree-insect interactions. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 27(8):1281-1290.*

The consequences of elevated CO2 for interactions between trees and associated insects will be influenced by the availability of other plant resources. We investigated the effects of CO2 and water availability on phytochemistry of quaking aspen (Populus tremuloides Michx.) and sugar maple (Acer saccharum Marsh.) and the associated performance of the forest tent caterpillar (Malacosoma disstria Hbn.). Seedlings were grown under ambient or elevated CO2 concentrations and under well-watered or drought conditions. We measured rates of gas exchange and subjected foliage to phytochemical assays. Bioassays were conducted to quantify larval performance on foliage from the various treatments. In general, elevated CO2 increased photosynthetic rates and had no effect on stomatal conductance, while drought reduced both parameters. Foliar nitrogen levels declined and secondary metabolite concentrations increased under enriched CO2, but starch and sugar levels were unaffected. All phytochemicals measured, with the exception of simple sugars, declined or did not change in response to drought. CO2- and drought-mediated changes in phytochemistry reduced forest tent caterpillar growth and food processing efficiencies, but the patterns were host-species specific. This work demonstrates that CO2 effects on forest trees will be mediated by the availability of water and that the direction and magnitude of responses will depend on the tree species involved, which will, in turn, affect patterns of host use by herbivorous insects.

KEYWORDS: CARBON DIOXIDE, ELEVATED CO2, GAS-EXCHANGE, GROWTH, HERBIVORE INTERACTIONS, LEPIDOPTERA, PHOTOSYNTHESIS, RESPONSES, SEEDLINGS, STRESS

2047

Rothschild, L.J. 1994. Elevated co2 - impact on diurnal patterns of photosynthesis in natural microbial ecosystems. *Life Sciences and Space Research XXV (3) 14(11):285-289.*

Algae, including blue-green algae (cyanobacteria), are the major source of fixed carbon in many aquatic ecosystems. Previous work has shown that photosynthetic carbon fixation is often enhanced in the presence of additional carbon dioxide (CO2). This study was undertaken to determine if this CO2 fertilization effect extended to microbial mats, and, if so, at what times during the day might the addition of CO2 affect carbon fixation. Four microbial mars from diverse environments were selected, including mars from a hypersaline pond (area 5, Exportadora de Sal, Mexico), the marine intertidal (Lyngbya, Laguna Ojo de Liebre, Mexico), an acidic hotspring (Cyanidium, Nymph Creek, Yellowstone National Park), and an acidic stream at ambient temperature (Zygogonium, Yellowstone National Park). Carbon fixation in the absence of additional CO2 essentially followed the rising and falling sunlight levels, except that during the middle of the day there was a short dip in carbon fixation rates. The addition of CO2 profoundly enhanced carbon fixation rates during the daylight hours, including during the midday dip. Therefore, it is unlikely that the midday dip was due to photoinhibition. Surprisingly, enhancement of carbon fixation was often greatest in the early morning or late afternoon, times when carbon fixation would be most likely to be light limited.

KEYWORDS: CARBON FIXATION, MARINE MACROALGAE, MAT, MODEL, OXYGENIC PHOTOSYNTHESIS

2048

Rotter, R., and S.C. Van de Geijn. 1999. Climate change effects on plant growth, crop yield and livestock. *Climatic Change 43(4):651-681.*

A review is given of the state of knowledge in the field of assessing climate change impacts on agricultural crops and livestock. Starting from the basic processes controlling plant growth and development, the possible impacts and interactions of climatic and other biophysical variables in different agro- environments are highlighted. Qualitative and quantitative estimations of shifts in biomass production and water relations, inter-plant competition and crop species adaptability are discussed. Special attention is given to the problems encountered when scaling up physiological responses at the leaf- and plant level to yield estimates at regional to global levels by using crop simulation models in combination with geo-referenced, agro-ecological databases. Some non-linear crop responses to environmental changes and their relations to adaptability and vulnerability of agro-ecosystems are discussed.

KEYWORDS: AIR- TEMPERATURE, ATMOSPHERIC CO2 ENRICHMENT, B RADIATION, ELEVATED CARBON-DIOXIDE, GLOBAL ENVIRONMENT CHANGE, LEAF-AREA, RESPONSES, TEMPERATURE-GRADIENT CHAMBERS, WATER-USE, WINTER-WHEAT

2049

Rotzel, C., P.W. Leadley, and C. Korner. 1997. Non-destructive assessment of the effects of elevated CO2 on plant community structure in a calcareous grassland. *Acta Oecologica-International Journal of Ecology 18(3):231-239.*

Calcareous grassland was exposed to ambient or elevated CO2 using a Screen-Aided CO2 Control (SACC) system starting in March 1994. The effects of elevated CO2 on plant community structure were studied using the paint intercept method. Measurements were made in March 1994 prior to the start of CO2 exposure and again in June 1994 at peak plant biomass. There were no significant differences in the initial structure of the communities based on their assigned CO2 treatments in March. After 9 weeks of exposure of the community to elevated CO2, the total number of intercepts per plot was not significantly different between CO2 treatments; however, Carex flacca and Cirsium acaule had marginally significant ($P = 0.055$ and $P = 0.06$) increases in the % sward of the community at elevated CO2 (number of intercepts for a single species divided by the total number of intercepts for all species). Measurements of leaf extension in Carex flacca showed that at least part of the increase in % sward at elevated CO2 could be explained by

greater leaf length per plant (P = 0.02). These measurements and other experiments with calcareous grassland species and communities suggest that rising atmospheric CO2 concentrations will probably alter the structure of calcareous grassland communities.

KEYWORDS: ATMOSPHERIC CO2, ENRICHMENT, GROWTH

2050

Rouhier, H., G. Billes, L. Billes, and P. Bottner. 1996. Carbon fluxes in the rhizosphere of sweet chestnut seedlings (Castanea sativa) grown under two atmospheric CO2 concentrations: C-14 partitioning after pulse labelling. *Plant and Soil 180(1):101-111.*

Partitioning of C-14 was assessed in sweet chestnut seedlings (Castanea sativa Mill.) grown in ambient and elevated atmospheric [CO2] environments during two vegetative cycles. The seedlings were exposed to (CO2)-C-14 atmosphere in both high and low [CO2] environments for a 6-day pulse period under controlled laboratory conditions. Six days after exposure to (CO2)-C-14, the plants were harvested, their dry mass and the radioactivity were evaluated. C-14 concentration in plant tissues, root-soil system respiratory outputs and soil residues (rhizodeposition) were measured. Root production and rhizodeposition were increased in plants growing in elevated atmospheric [CO2]. When measuring total respiration, i.e. CO2 released from the root/soil system, it is difficult to separate CO2 originating from roots and that coming from the rhizospheric microflora. For this reason a model accounting for kinetics of exudate mineralization was used to estimate respiration of rhizospheric microflora and roots separately. Root activity (respiration and exudation) was increased at the higher atmospheric CO2 concentration. The proportion attributed to root respiration accounted for 70 to 90% of the total respiration. Microbial respiration was related to the amount of organic carbon available in the rhizosphere and showed a seasonal variation dependent upon the balance of root exudation and respiration. The increased carbon assimilated by plants grown under elevated atmospheric [CO2] stayed equally distributed between these increased root activities.

KEYWORDS: DIOXIDE, ELEVATED CO2, ENRICHMENT, MICROBIAL BIOMASS, NITROGEN, RESPIRATION, ROOT, SOIL, SPRING WHEAT, TURNOVER

2051

Rouhier, H., G. Billes, A. Elkohen, M. Mousseau, and P. Bottner. 1994. Effect of elevated co2 on carbon and nitrogen distribution within a tree (castanea-sativa mill) soil system. *Plant and Soil 162(2):281-292.*

Two-year-old sweet chestnut trees were grown outside in normal or double CO2 atmospheric concentration. In spring and in autumn of two growing seasons, a six day labelling pulse of C- 14 labelled CO2 was used to follow the carbon assimilation and distribution in the plant-soil system. Doubling atmospheric CO2 had a significant effect on the tree net carbon uptake. A large proportion of the additional C uptake was 'lost' through the root system. This suggests that increased C uptake under elevated CO2 conditions increases C cycling without necessarily increasing C storage in the plant. Total root derived material represented a significant amount of the 'extra-assimilated' carbon due to the CO2 treatment and was strongly correlated with the phenological stage of the tree. Increasing root rhizodeposition led to a stimulation of microbial activity, particularly near the end of the growing season. When plant rhizodeposition was expressed as a function of the root dry weight, the effect of increasing CO2 resulted in a higher root activity. The C to N ratios were significantly higher for trees grown under elevated CO2 except for the fine root compartment. An evaluation of the plant-soil system nitrogen dynamics showed, during the second season of CO2 treatment, a decrease of soil N mineralization rate and total N uptake for trees grown at elevated CO2 levels.

KEYWORDS: ATMOSPHERIC CO2, DIOXIDE, ENRICHMENT, GROWTH, PLANTS, QUERCUS-ALBA, RESPIRATION, RHIZOSPHERE, SEEDLINGS, TURNOVER

2052

Rouhier, H., and D.J. Read. 1998. Plant and fungal responses to elevated atmospheric carbon dioxide in mycorrhizal seedlings of Pinus sylvestris. *Environmental and Experimental Botany 40(3):237-246.*

The effects of elevated CO2 concentration upon the mycorrhizal relationships of Scots pine (Pinus sylvestris) seedlings were investigated. Plants were grown for 4 months with their shoots exposed to ambient (C-AMB = 360 mu l l(-1)) or elevated (C-ELEV = 700 mu l l(-1)) CO2 environments while their root systems, either colonised by the mycorrhizal fungi Paxillus involutus or Suillus bovinus, or left in the non-mycorrhizal condition, were maintained in sealed dishes. In one series of these plants the effects of C-ELEV upon the extent of mycorrhizal development and upon their growth and nutrition were determined, while another series were transferred from the dishes after 1 month, to transparent observation chambers before being returned to the two CO2 environments. In these chambers, the effects of C- ELEV upon development of the external mycelial systems of the two mycorrhizal fungi was determined by measuring the advance of the hyphal fronts of the mycorrhizal fungi across non- sterile peat from the colonised plants. The dry mass and number of mycorrhizal tips were significantly higher in C-ELEV than in the C-AMB condition in plants colonised by both fungi in the dishes. Yields of whole plants and of shoots were higher in the C-ELEV treatment whether or not they were grown in the mycorrhizal condition, but the greater yields were not associated in these sealed systems with enhanced nutrient gain. The dry mass of non-mycorrhizal plants was greater than that of those colonised by mycorrhizal fungi under elevated CO2. This is thought to be attributable to the energetic cost of production of the larger mycorrhizal systems in this treatment. The extent of development of the mycorrhizal mycelial systems of both fungi was greatly increased in C-ELEV relative to that in C-AMB environments. It is hypothesised that increased allocation of carbon to mycorrhizal root systems and their associated mycelia would provide the potential for enhancement of nutrient acquisition in open systems of greater fertility.

KEYWORDS: CO2, DYNAMICS, ECTOMYCORRHIZAL COLONIZATION, GROWTH, JUVENILE PONDEROSA PINE, MYCELIUM, NITROGEN, ROOTS, SOIL N

2053

Rouhier, H., and D.J. Read. 1998. The role of mycorrhiza in determining the response of Plantago lanceolata to CO2 enrichment. *New Phytologist 139(2):367-373.*

Plantago lanceolata L. was grown for 104 d with (M) or without (NM) arbuscular mycorrhizal colonization under conditions of ambient (C-AMB = 350 mu l l(-1)) and elevated (C-ELEV = 540 mu l l(-1)) CO2. Sequential harvests (H) were taken at 41 (H-1), 76 (H-2) and 104 d (H-3) to determine the time-course of mycorrhizal influence on the response of the plant to CO2 enrichment. Total yields of M plants were greater than those of NM from H-2 onwards. Plants in the M-ELEV treatment were significantly larger than those in the M-AMB at 104 d. There were significant but much smaller differences in yield between NMELEV and NMAMB. The differences in total yield arose through impact of C-ELEV on both shoots and roots. Total root length was greater in M-ELEV than in M-AMB only at H-3, but total length of mycorrhizal root was greater at H-2 and H-3. The percentages of root length colonized and that occupied by arbuscules and vesicles were greater in M-ELEV than in M-AMB at the last two harvests, indicating increased sequestration of carbon in internal fungal structures. Though extraradical

hyphal lengths were greater in M-ELEV than in M-AMB at H-2 and H-3, the differences were not significant. Phosphorus inflow and P content of M plants were higher than those of NM plants at H-2 and H-3, and were higher in M-ELEV than in M-AMB at H-3. ANOVA revealed no significant interactions between CO2 and mycorrhizal treatment. The results are discussed in relation to carbon sequestration in mycorrhizal systems and likely impacts of CO2 enrichment on P. lanceolata grown under field conditions. The importance of sequential harvesting for realistic determination of responses to CO2 is stressed.

KEYWORDS: BOUTELOUA-GRACILIS, CARBON DIOXIDE, COLONIZATION, COMMUNITY, DIVERSITY, ECOSYSTEMS, ELEVATED ATMOSPHERIC CO2, FUNGI, RHIZOSPHERE, ROOTS

2054

Rouhier, H., and D.J. Read. 1999. Plant and fungal responses to elevated atmospheric CO2 in mycorrhizal seedlings of Betula pendula. *Environmental and Experimental Botany 42(3):231-241.*

The effects of elevated CO2 concentrations upon carbon allocation in mycorrhizal (M) and non-mycorrhizal (NM) birch (Betula pendula) seedlings were investigated. M plants, colonised by the fungus Paxillus involutus, and NM plants, were exposed for 3 months to ambient (350 mu l 1(-1)) or elevated (700 mu l 1(-1)) CO2 environments. The assimilation and distribution of carbon within the different compartments of the plant-substrate-fungal system were investigated using radioactive carbon as a tracer. In addition, the impact of elevated CO2 upon extension growth of the ectomycorrhizal mycelium of the fungus was determined in transparent observation chambers. Yields of whole plants and of shoots were significantly decreased under elevated CO2 whether they were grown with or without their fungal symbionts. Neither the dry mass production of roots of mycorrhizal plants, nor the amount of carbon allocated to shoots, roots and mycorrhizal tips were affected by elevated CO2. While the number of mycorrhizal root tips was decreased with CO2 enrichment, their relative importance in the total root system was unchanged. There was a significant increase in the extent of development of the external mycelium under elevated CO2. A greater proportion of the radioactive carbon was allocated to the soil compartment under elevated CO2. This increase, probably arising through increased rhizodeposition, was greater in NM than M plants. The responses are discussed in terms of nutrient availability in the growth media and the possible role of increased carbon allocation to mycorrhizal mycelium in nature.

KEYWORDS: ALLOCATION, AVAILABILITY, CARBON-DIOXIDE CONCENTRATION, COLONIZATION, ENRICHMENT, GROWTH, NITROGEN, PHOTOSYNTHESIS, PINE SEEDLINGS, ROTH

2055

Roumet, C., M.P. Bel, L. Sonie, F. Jardon, and J. Roy. 1996. Growth response of grasses to elevated CO2: A physiological plurispecific analysis. *New Phytologist 133(4):595-603.*

The effect of CO2 enrichment on the growth and the economy of carbon and nitrogen of 11 Mediterranean grass species was investigated in order to determine the underlying causes of the large variation observed between species in their responses to elevated CO2. Plants were grown for 26-43 d (depending on species growth rate) under productive conditions at ambient (350 mu mol mol(-1)) and elevated (700 mu mol mol(-1)) concentrations of CO2. Plant parameters were determined at a common biomass of 0.15 g to determine the CO2 effect independent of ontogenic effects. The effect of CO2 on RGR ranged from -6.7 to 22.5%, with a mean stimulation of 10.3%. Averaged over the 11 species, the growth enhancement resulted from an increase in net assimilation rate per unit leaf d. wt. (NAR(w)) of 10.6%. This was the result of a large increase (18.7%) in NAR per unit leaf area (NAR(a)) associated with a 8.1% decrease in the specific leaf area (SLA). This decrease in SLA was due to a large increase of the non-structural carbohydrates. The increase in shoot activity was balanced by a 7.6% increase in the specific absorption rate of nitrogen (SAR). AS a result, plant nitrogen content was not modified. Leaf nitrogen productivity was significantly increased (14.9%). Shoot vs. root allocation of biomass and nitrogen was not modified. An analysis across the 11 species of the relationships between the stimulation of RGR and the alteration in RGR components showed a significant correlation only with increases in NAR(w), SAR and nitrogen productivity. The co- ordinated increase in these three parameters constitutes a single response syndrome, whose intensity is responsible for most of the species variability.

KEYWORDS: ATMOSPHERIC CO2, BIOMASS ALLOCATION, C-3, CARBON DIOXIDE, ENRICHMENT, NITROGEN CONCENTRATION, NUTRITION, PHOTOSYNTHESIS, PLANT GROWTH, ROOT

2056

Roumet, C., G. Laurent, and J. Roy. 1999. Leaf structure and chemical composition as affected by elevated CO2: genotypic responses of two perennial grasses. *New Phytologist 143(1):73-81.*

Genotypic variability was studied in two Mediterranean grass species, Bromus erectus and Dactylis glomerata, with regard to the response to CO2 of leaf total non-structural carbohydrate concentration ([TNC](1f)), specific leaf area (SLA), and leaf carbon and nitrogen concentrations ([C](1f) and [N](1f), respectively). Fourteen genotypes of each species were grown together on intact soil monoliths at ambient and elevated CO2 concentrations (350 and 700 mu mol mol(-1), respectively). In both species, the most consistent effect of elevated CO2 was an increase in [TNC](1f) and a decrease in leaf nitrogen concentration when expressed either as total dry mass [N- m](1f), structural dry mass [N(m)st](1f) or leaf area [N- a](1f). The SLA decreased only in D, glomerata, due to an accumulation of total nonstructural carbohydrates and to an increase in leaf density. No genotypic variability was found for any variable in B. erectus, suggesting that genotypes responded in a similar way to elevated CO2. In D. glomerata, a genotypic variability was found only for [Cst], [N-m](1f), [N(m)st](1f) and [N-a](1f). Since [N-m](1f) is related to plant growth and is a strong determinant of plant-herbivore interactions, our results suggest evolutionary consequences of elevated CO2 through competitive interactions or herbivory.

KEYWORDS: ARABIDOPSIS-THALIANA, ATMOSPHERIC CO2, CARBON DIOXIDE, ENRICHMENT, GROWTH-RESPONSE, INTRASPECIFIC VARIATION, LITTER QUALITY, NITROGEN CONCENTRATION, NUTRIENT, PLANTAGO-MAJOR

2057

Roumet, C., and J. Roy. 1996. Prediction of the growth response to elevated CO2: A search for physiological criteria in closely related grass species. *New Phytologist 134(4):615-621.*

Using 11 closely related grass species, we tested the capacity of physiological criteria to predict the growth response to elevated CO2 and to categorize the species with regard to their CO2 response. A growth analysis was conducted under productive conditions both at ambient (350 mu mol mol(-1)) and elevated (700 mu mol mol(-1)) CO2. The relative growth rate stimulation was regressed against each of the growth rate components measured at ambient CO2. Growth response to CO2 was positively correlated with specific leaf area (SLA, the leaf surface area per unit of leaf weight), leaf area ratio (the leaf area per unit of total plant dry weight) and negatively correlated with net assimilation rate and leaf nitrogen concentration, both per unit of leaf area. We suggest that SLA has a predominant role in these relationships. Different hypotheses are proposed and discussed in order to explain why species with low

SLA are less responsive to elevated CO2. Neither biomass allocation, relative growth rate, shoot or root specific activities per unit of mass, nor chemical composition were significantly correlated with growth response to CO2. The four predictive criteria mentioned above coherently differentiate the five wild annual species (higher SLA, stronger growth response to CO2) from the four wild perennials. The two perennial crop species, with the highest SLA, were more responsive than the wild species.

KEYWORDS: AMBIENT, ARABIDOPSIS-THALIANA, ASSIMILATION RATE, BIOMASS, CARBON-DIOXIDE ENRICHMENT, LEAVES, NITROGEN, PHOTOSYNTHESIS, PLANTS, TEMPERATURE

2058

Roussopoulos, D., A. Liakatas, and W.J. Whittington. 1998. Cotton responses to different light-temperature regimes. *Journal of Agricultural Science 131:277-283.*

A series of experiments investigating the interactive effects of light and temperature on vegetative growth, earliness, fruiting, yield and fibre properties in three cultivars of cotton, was undertaken in growth rooms. Two constant day/night temperature regimes with a difference of 4 degrees C (30/20 and 26/16.5 degrees C) were used throughout the growing season in combination with two light intensities (75 and 52.5 W m(-2)). The results showed that significant interactions occurred for most of the characters studied. Although the development of leaf area was mainly temperature-dependent, plants at harvest had a larger leaf area when high temperature was combined with low rather than with high light intensity. Leaf area was least in the low temperature-low light regime. However, the plants grown under the high temperature-low light combination weighed the least. Variations in the number of nodes and internode length were largely dependent on temperature rather than light. Light did, however, affect the numbers of branches, sympodia and monopodia. The first two of these were highest in the high light-high temperature regime and the third in the low light- low temperature regime. All other characters, except time to certain developmental stages and fibre length, were reduced at the lower light intensity. Variation in temperature modified the light effect and vice versa, in a character-dependent manner. More specifically, square and boil dry weights, as well as seed cotton yield per plant, were highest in high light combined with low temperature, where the most and heaviest bells were produced. But flower production was favoured by high light and high temperature, suggesting increased boil retention at low temperature, especially when combined with low light. Low temperature and high light also maximized lint percentage. Fibres were shortest in the high temperature-high light regime, where fibre strength, micronaire index and maturity ratio were at a maximum. However, the finest and the most uniform fibres were produced when high light was combined with low temperature. Cultivar differences were significant mainly in leaf area and dry matter production at flowering.

KEYWORDS: AIR CO-2 ENRICHMENT, CANOPY PHOTOSYNTHESIS, FIELD, GROWTH, LEAF CONDUCTANCE, LEAVES, RESPIRATION, TRANSPIRATION, WATER-STRESS

2059

Rowlandbamford, A.J., L.H. Allen, J.T. Baker, and K.J. Boote. 1990. Carbon-dioxide effects on carbohydrate status and partitioning in rice. *Journal of Experimental Botany 41(233):1601-1608.*

The atmospheric carbon dioxide (CO2) concentration has been rising and is predicted to reach double the present concentration sometime during the next century. The objective of this investigation was to determine the long-term effects of different CO2 concentrations on carbohydrate status and partitioning in rice (Oryza sativa L. cv. IR-30). Rice plants were grown season-long in outdoor, naturally sunlit, environmentally controlled growth chambers with CO2 concentrations of 160, 250, 330, 500, 660, and 900 mu-mol CO2 mol-1 air. In leaf blades, the priority between the partitioning of carbon into storage carbohydrates or into export changed with development stage and CO2 concentration. During vegetative growth, leaf sucrose and starch concentrations increased with increasing CO2 concentration but tended to level off above 500 mu-mol mol-1 CO2. Similarly, photosynthesis also increased with CO2 concentrations up to 500 mu-mol mol-1 and then reached a plateau at higher concentrations. The ratio of starch to sucrose concentration was positively correlated with the CO2 concentration. At maturity, increasing CO2 concentration resulted in an increase in total non-structural carbohydrate (TNC) concentration in leaf blades, leaf sheaths and culms. Carbohydrates that were stored in vegetative plant parts before heading made a smaller contribution to grain dry weight at CO2 concentrations below 330 mu-mol mol-1 than for treatments at concentrations above ambient. Increasing CO2 concentration had no effect on the carbohydrate concentration in the grain at maturity.

KEYWORDS: CO2, ENRICHMENT, GROWTH, NITROGEN, PHOTOSYNTHESIS, PLANTS, STARCH, YIELD

2060

Rowlandbamford, A.J., J.T. Baker, L.H. Allen, and G. Bowes. 1991. Acclimation of rice to changing atmospheric carbon-dioxide concentration. *Plant, Cell and Environment 14(6):577-583.*

The effects were studied of season-long (75 and 88 d) exposure of rice (Oryza sativa L. cv. IR-30) to a range of atmospheric CO2 concentrations in outdoor, computer-controlled, environment chambers under natural solar radiation. The CO2 concentrations were maintained at 160, 250, 330, 500, 660 and 900-mu-mol mol-1 air. Photosynthesis increased with increasing growth CO2 concentrations up to 500-mu-mol mol-1, but levelled off at higher CO2 values. Specific leaf area also increased significantly with increasing CO2. Although leaf dry weight and leaf area index increased, the overall response was not statistically significant. Leaf nitrogen content dropped slightly with elevated CO2, but the response was not statistically significant. The specific activity of ribulose bisphosphate carboxylase/oxygenase (rubisco) declined significantly over the CO2 concentration range 160 to 900-mu- mol mol-1. When expressed on a leaf area basis, rubisco activity decreased by 66%. This was accompanied by a 32% decrease in the amount of rubisco protein as a fraction of the total soluble leaf protein, and by 60% on a leaf area basis. For leaves in the dark, the total rubisco activity (CO2/Mg2+- activated) was reduced by more than 60%. This indicates that rice accumulated an inhibitor in the dark, probably 2-carboxyarabinitol 1-phosphate (CA-1-P). However, the inhibitor did not seem to be involved in the acclimation response. The degree of carbamylation of the rubisco enzyme was unchanged by the CO2 growth regime, except at 900-mu-mol mol-1 where it was reduced by 24%. The acclimation of rice to different atmospheric CO2 conditions involved the modulation of both the activity and amount of rubisco protein in the leaf.

KEYWORDS: ACTIVATION, ENRICHMENT, GROWTH, HIGH CO2, INHIBITOR, LIGHT, MONOECIOUS CUCUMBERS, PHOTOSYNTHESIS, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, SOYBEAN LEAVES

2061

RowlandBamford, A.J., J.T. Baker, L.H. Allen, and G. Bowes. 1996. Interactions of CO2 enrichment and temperature on carbohydrate accumulation and partitioning in rice. *Environmental and Experimental Botany 36(1):111-124.*

The objective of this study was to determine the long-term effects of CO2 concentration and temperature on carbohydrate partitioning and

status in rice (Oryza sativa L. cv. IR-30). The plants were grown season-long in sunlit, controlled- environment chambers with CO2 concentrations of 330 or 660 mu mol mol(-1), and daytime air temperatures of 28, 34 or 40 degrees C. In leaf blades, the priority between partitioning of carbon into storage or into export changed with CO2 concentration and temperature. Leaf sucrose concentration increased with CO2 enrichment at all temperature regimes. Over the season, elevated CO2 resulted in an increase in total non- structural carbohydrate (TNC) concentration in leaf blades, leaf sheaths and culms at all temperature treatments. Elevated CO2 had no effect on carbohydrate concentration in the grain at maturity, however, grain TNC concentration was significantly lowered by increasing temperature. Under the highest temperature regime, the plants in the 330 mu mol mol(-1) CO2 treatment died during stem extension while the CO2 enriched plants survived but produced sterile panicles. The results suggest that CO2-enriched plants could survive and maintain carbohydrate production rates at higher temperatures than the non-enriched plants; however, the optimum temperature for TNC accumulation was 28 degrees C at both CO2 concentrations.

KEYWORDS: AIR- TEMPERATURE, CARBON-DIOXIDE CONCENTRATION, CLIMATE SENSITIVITY, GROWTH, LEAVES, MODEL, OCEAN, RESPONSES

2062

Rozema, J. 1993. Plant-responses to atmospheric carbon-dioxide enrichment - interactions with some soil and atmospheric conditions. *Vegetatio 104:173-190.*

In general, C3 plant species are more responsive to atmospheric carbon dioxide (CO2) enrichment than C4-plants. Increased relative growth rate at elevated CO2 primarily relates to increased Net Assimilation Rate (NAR), and enhancement of net photosynthesis and reduced photorespiration. Transpiration and stomatal conductance decrease with elevated CO2, water use efficiency and shoot water potential increase, particularly in plants grown at high soil salinity. Leaf area per plant and leaf area per leaf may increase in an early growth stage with increased CO2, after a period of time Leaf Area Ratio (LAR) and Specific Leaf Area (SLA) generally decrease. Starch may accumulate with time in leaves grown at elevated CO2, Plants grown under salt stress with increased (dark) respiration as a sink for photosynthates, may not show such acclimation to increased atmospheric CO2 levels. Plant growth may be stimulated by atmospheric carbon dioxide enrichment and reduced by enhanced UV-B radiation but the limited data available on the effect of combined elevated CO2 and ultraviolet B (280-320 nm) (UV-B) radiation allow no general conclusion. CO2-induced increase of growth rate can be markedly modified at elevated UV-B radiation. Plant responses to elevated atmospheric CO2 and other environmental factors such as soil salinity and UV-B tend to be species-specific, because plant species differ in sensitivity to salinity and UV-B radiation, as well as to other environmental stress factors (drought, nutrient deficiency). Therefore, the effects of joint elevated atmospheric CO2 and increased soil salinity or elevated CO2 and enhanced UV-B to plants are physiologically complex.

KEYWORDS: AIR- TEMPERATURE, B RADIATION, CO2-ENRICHMENT, DIFFERENT IRRADIANCES, ELEVATED CO2, ESTUARINE MARSH, GROWTH, PHOTOSYNTHESIS, STRESS, WATER RELATIONS

2063

Rozema, J., F. Dorel, R. Janissen, G. Lenssen, R. Broekman, W. Arp, and B.G. Drake. 1991. Effect of elevated atmospheric CO2 on growth, photosynthesis and water relations of salt-marsh grass species. *Aquatic Botany 39(1-2):45-55.*

The C3 grass species Scirpus maritimus L. and Puccinellia maritima (Huds.) Parl., and the C4 grass species Spartina anglica C.E. Hubbard and Spartina patens (Ait.) Muhl. were grown at ambient (340 p.p.m. CO2) and elevated (580 p.p.m. CO2) atmospheric CO2 concentration, at low (10 mM NaCl) and high salinity (250 mM NaCl) under aerated and anaerobic conditions in the culture solution. The relative growth rate of both the C3 grass species was enhanced with atmospheric CO2 enrichment, no such increase was found in the C4 grass species. High salinity reduced growth of the C3 species tested, but this relative growth reduction was not prevented by elevated CO2 concentration. The growth increase at elevated CO2 of Scirpus maritimus and Puccinellia maritima is greater under aerated than under anaerobic solution conditions. Water-use efficiency of all species was increased by elevated CO2. In the case of Scirpus (C3), this increase was caused by increased net photosynthesis, for Spartina patens (C4) photosynthesis was not increased, but transpiration was reduced. The water potential of the shoot was less negative under conditions of CO2 enrichment, in particular at increased salinity (250 mM NaCl).

KEYWORDS: C-4 PLANTS, CARBON DIOXIDE, ENRICHMENT, ESTUARINE MARSH, NITROGEN, PLANT GROWTH, TEMPERATURE

2064

Rozema, J., G.M. Lenssen, J.W.M. vandeStaaij, M. Tosserams, A.J. Visser, and R.A. Broekman. 1997. Effects of UV-B radiation on terrestrial plants and ecosystems: Interaction with CO2 enrichment. *Plant Ecology 128(1-2):182-191.*

UV-B radiation is just one of the environmental factors, that affect plant growth. It is now widely accepted that realistic assessment of plant responses to enhanced UV-B should be performed at sufficiently high Photosynthetically Active Radiation (PAR), preferably under field conditions. This will often imply, that responses of plants to enhanced UV-B in the field will be assessed under simultaneous water shortage, nutrient deficiency and variation of temperature. Since atmospheric CO2 enrichment, global warming and increasing UV-B radiation represent components of global climatic change, interactions of UV-B with CO2 enrichment and temperature are particularly relevant. Only few relevant UV-B x CO2 interaction studies have been published. Most of these studies refer to greenhouse experiments. We report a significant CO2 x UV-B interaction for the total plant dry weight and root dry weight of the C-3-grass Elymus athericus. At elevated CO2 (720 mu mol mol(-1)), plant growth was much less reduced by enhanced UV-B than at ambient atmospheric CO2 although there were significant (positive) CO2 effects and (negative) UV-B effects on plant growth. Most other CO2 x UV-B studies do not report significant interactions on total plant biomass. This lack of CO2 x UV-B interactions may result from the fact that primary metabolic targets for CO2 and UVB are different. UV-B and CO2 may differentially affect plant morphogenetic parameters: biomass allocation, branching, flowering, leaf thickness, emergence and senescence. Such more subtle interactions between CO2 and UV-B need careful and long term experimentation to be detected. In the case of no significant CO2 x UV-B interactions, combined CO2 and UV-B effects will be additive. Plants differ in their response to CO2 and UV-B, they respond in general positively to elevated CO2 and negatively to enhanced UV-B. Moreover, plant species differ in their responsiveness to CO2 and UV-B. Therefore, even in case of additive CO2 and UV-B effects, plant competitive relationships may change markedly under current climatic change with simultaneous enhanced atmospheric CO2 and solar UV-B radiation.

KEYWORDS: CARBON-DIOXIDE ENRICHMENT, ENHANCEMENT, GROWTH, PHOTOSYNTHESIS, RICE

2065

Rudorff, B.F.T., C.L. Mulchi, C.S.T. Daughtry, and E.H. Lee. 1996.

Growth, radiation use efficiency, and canopy reflectance of wheat and corn grown under elevated ozone and carbon dioxide atmospheres. *Remote Sensing of Environment 55(2):163-173.*

Estimates of increases in future agricultural production in response to increases in carbon dioxide (CO2) concentrations in the atmosphere are often based on the beneficial physiological effect of CO2 enrichment on plant growth, especially in C-3 plants. However, these estimates fail to consider the negative impact of ozone (O-3) air pollution on crop production. Increases in tropospheric concentrations of both gases, CO2 and O-3, have been observed over the past century, and both are predicted to continue to increase at even higher rates in the near future to levels when they may have a significant impact on agricultural production. Field studies with wheat (Triticum aestivum L.) in 1991 and 1992, and corn (Zea mays L.) in 1991 were conducted using open-top chambers to mimic atmospheric concentrations of CO2 (similar to 500 mu L(-1) CO2) and O-3 (similar to 40 nL L(-1) O-3 above ambient air [O-3] during 7h day(-1) 5 days week(-1)) that are predicted to occur at the Earth surface during the first half of the 21st century. Wheat and corn (C-3 vs. C-4) produced clearly different responses to CO2 enrichment, but similar responses to O-3 exposure. In wheat, O-3 exposure led to reduced grain yield, biomass, and radiation use efficiency (RUE, phytomass production per unit of energy received); in both years; but reduction in accumulated absorbed photosynthetically active radiation (AAPAR) was observed only in 1991. Conversely, CO2 enrichment produced greater grain yield, dry biomass, and RUE. With CO2 enrichment, the O-3-induced stress to wheat plants was apparently ameliorated since responses were equivalent to the control group (low O-3 and ambient CO2) for all variables. In contrast, corn demonstrated no benefit to CO2 enrichment for measured variables, and corn grain yield was the only parameter negatively influenced by O-3 exposure that is attributed to O- 3-induced damage during the flowering process. Additionally, no treatment differences were observed for leaf area index (LAI) as determined nondestructively using the LICOR LAI-2000 Plant Canopy Analyzer. Also, treatment differences for normalized difference vegetation index (ND) were only observed for wheat plants from the high-O-3 and ambient-CO2 treatment, at some growing stages. Otherwise, ND were not helpful for identifying damage due to O-3 fumigation or benefits due to CO2 enrichment. Significant interactive effects of CO2 vs. O-3 were observed only for wheat grain yield in 1991 ($p < 0.10$), indicated that the detrimental effect of O-3 air pollution was more than overcome under the CO2-enriched environment.

KEYWORDS: BIOMASS, CHAMBERS, CO2, FIELD, O-3, RESPONSES, VEGETATION

2066

Rudorff, B.F.T., C.L. Mulchi, P. Fenny, E.H. Lee, and R. Rowland. 1996. Wheat grain quality under enhanced tropospheric CO2 and O-3 concentrations. *Journal of Environmental Quality 25(6):1384-1388.*

It is expected that the progressive increase of tropospheric trace gases such as CO2 and O-3 will have a significant impact on agricultural production. The single and combined effects of CO2 enrichment and tropospheric O-3 on grain quality characteristics in soft red winter wheat (Triticum aestivum L.) were examined in held studies using 3 m in diam. open-top chambers. Wheat cultivars 'Massey' (1991) and 'Saluda' (1992) were exposed to two CO2 concentrations (350 vs. 590 mu mol CO2 mol(-1); 12 h d(-1)) in combination with two O-3 regimes (charcoal-filtered air vs. ambient air + 40 +/- 20 nmol O-3 mol(-1), 7 h d(-1) Monday to Friday) from late March until maturity in June. Grain quality characteristics investigated included: test weight, milling and baking quality, flour yield, protein content, softness equivalent, alkaline water retention capacity, and cookie diameter. In general, exposure of plants to either elevated CO2 or weekly chronic O-3 episodes caused only small changes in grain quality. Milling and baking quality score were not significantly changed in response to treatments in both years. Flour yield was increased by elevated CO2 but this increase was counteracted when elevated CO2 was combined with chronic O-3 exposure. Flour protein contents were increased by enhanced O-3 exposure and reduced by elevated CO2. Softness equivalent was increased by 2.4% by enhanced O-3 exposure but unaffected by O-3 under elevated CO2. Although the single effect of either CO2 enrichment or chronic O-3 exposure had some impact on grain quality characteristic, it was noted that the combined effect of these gases was minor. It is Likely that the concomitant increase of CO2 and O-3 in the troposphere will have no significant impact on wheat grain quality.

KEYWORDS: FIELD, OPEN-TOP CHAMBERS, OZONE, RED WINTER-WHEAT, RESPONSES, VEGETATION, YIELD

2067

Rudorff, B.F.T., C.L. Mulchi, E.H. Lee, R. Rowland, and R. Pausch. 1996. Effects of enhanced O-3 and CO2 enrichment on plant characteristics in wheat and corn. *Environmental Pollution 94(1):53-60.*

The effects of CO2 enrichment and O-3 induced stress on wheat (Triticum aestivum L.) and corn (Zea mays L.) were studied in field experiments using open-top chambers to simulate the atmospheric concentrations of these two gases that are predicted to occur during the coming century. The experiments were conducted at Beltsville, MD, during 1991 (wheat and corn) and 1992 (wheat). Crops were grown under char coal filtered (CF) air or ambient air +40 nl liter(-1) O-3 (7 h per day, 5 days per week) having ambient CO2 concentration (350 mu l liter(-1) CO2) or +150 mu l liter(-1) CO2 (12 h per day). Averaged over O-3 treatments, the CO2-enriched environment had a positive effect on wheat grain yield (26% in 1991 and 15% in 1992) and dry biomass (15% in 1991 and 9% in 1992). Averaged over CO2 treatments, high O-3 exposure had a negative impact on wheat grain yield (-15% in 1991 and -11% in 1992) and drill biomass (-11% in 1991 and -9% in 1992). Averaged over CO2 treatments, high O-3 exposure decreased corn grain yield by 9%. No significant interactive effects were observed for either crop. The results indicated that CO2 enrichment had a beneficial effect in wheat (C-3 crop) but not in corn (C-4 crop). It is likely that the O-3-induced stress will be diminished under increased atmospheric CO2 concentrations; however, maximal benefits in crop production in wheat in response to CO2 enrichment will not be materialized under concomitant increases in tropospheric O-3 concentration.

KEYWORDS: CHRONIC OZONE, CROP YIELD, DRY-MATTER, ELEVATED CARBON-DIOXIDE, GRAIN QUALITY, INCREASED ATMOSPHERIC CO2, RED WINTER-WHEAT, SPRING WHEAT, TOP FIELD CHAMBERS, TRITICUM-AESTIVUM L

2068

Rudorff, B.F.T., C.L. Mulchi, E. Lee, R. Rowland, and R. Pausch. 1996. Photosynthetic characteristics in wheat exposed to elevated O-3 and CO2. *Crop Science 36(5):1247-1251.*

Tropospheric trace gases such as CO2 and O-3 have progressively increased over the past century and are predicted to increase to levels at which they may have a significant impact on agricultural production. The effects of CO2 enrichment and O-3 air pollution on leaf photosynthesis (P-n) and stomatal conductance (g(s)) were investigated. Two soft red winter wheat (Triticum aestivum L.) cultivars, Massey in 1991 and Saluda in 1992, were studied in field experiments at Beltsville, RID, by means of open-top chambers to mimic atmospheric environments predicted for the first half of the 21st century. Plants were exposed to two levels of O-3 (charcoal filtered air and ambient air + an average of 40 nnol O-3 mol(-1) from Monday-Friday of every week). Ozone treatments were superimposed on two CO2 treatments (350 mu mol CO2 mol(-1) and 500 mu mol CO2 mol(-1)). Averaged over O-3

treatments, P-n was stimulated during the early and late growing season under enriched CO2. Averaged over CO2 treatments, high O-3 exposure had a negative impact on P-n early in the season of 1992 and a major impact late in the season of 1991 and 1992 due to premature senescence. Decreases in g(s) occurred under the enriched CO2 environment and to a lesser extent with high O-3. Interactive effects on P-n, and g(s) were mostly absent. It is likely that if CO2 and O-3 concentrations continue to increase, the beneficial effect of CO2 enrichment on P-n may be partially negated by O-3-induced stress. Conversely, damaging effects of O-3 on P-n may be compensated by elevated atmospheric CO2.

KEYWORDS: AIR- POLLUTANTS, ATMOSPHERIC CO2, CARBON DIOXIDE, FIELD, GAS-EXCHANGE, GROWTH, OZONE, PLANTS, RADIATION, RESPONSES

2069

Rufty, T.W., R.B. Thomas, J.D. Cure, and W.W. Cure. 1994. Growth-response of cotton to co2 enrichment in differing light environments. *Physiologia Plantarum 91(3):503-509.*

Experiments were conducted to examine the growth responses of cotton (Gossypium hirsutum L. cv. Coker 315) to CO2 enrichment under different light regimes. Plants were exposed to 350 or 700 mu l(-1) CO2 and six light treatments differing in photosynthetic period length (8 or 16 h) and in photosynthetic photon flux density (PPFD) for 32 days of vegetative growth. Higher PPFD (1100 mu mol m(-2) s(-1)) was provided by a combination of high intensity discharge and incandescent lamps (HID), and lower PPFD (550 mu mol m(-2) s(-1)) was provided by fluorescent and incandescent lamps (F) or HID and incandescent lamps with shade cloth (HIDs). Growth was generally much slower with the 8-h photosynthetic periods, but the growth stimulation by CO2 enrichment was larger than with 16-h photosynthetic periods. After 28 to 32 days of treatment, the growth enhancement with CO2 enrichment was 152 and 78% for 8- and 16-h photosynthetic periods, respectively, under HID; 100 and 77% in F, and 77 and 56% in HIDs. The higher PPFD of HID positively influenced the CO2 effect only at the slower growth rate in the 8-h light period. The stimulation of leaf area expansion by CO2 enrichment was also greater with the 8-h photosynthetic period for all light sources. These results, and others on net assimilation rate, shoot to root dry weight ratios and specific leaf weights, suggest that the growth response to CO2 enrichment with the longer photosynthetic period was depressed by limiting factors, perhaps nutritional, in the growth environment. The results also show that extensive variability in CO2 response can occur under light intensities which are often used in growth chamber experiments.

KEYWORDS: DRY-MATTER, ELEVATED CARBON-DIOXIDE, EXPANSION, LEAVES, NITROGEN STRESS, PHOTOSYNTHETIC ACCLIMATION, SEEDLINGS, SOYBEAN PLANTS, YIELD

2070

Ruget, F., O. Bethenod, and L. Combe. 1996. Repercussions of increased atmospheric CO2 on maize morphogenesis and growth for various temperature and radiation levels. *Maydica 41(3):181-191.*

The effect of atmospheric CO2 enhancement on maize production was studied through four crops in two glasshouse compartments, with and without CO2 enrichment. Development (number of organs, duration of phenological phases) was measured during cultivation and growth (dry matter production) was measured at flowering and at final harvest. The main results were as follows: The number of initiated organs (florets and leaves) was not affected by the CO2 enrichment. According to the runs, aerial and whole plant production were significantly or not increased in the enriched compartment. The production increase was significantly different bem een treatments under poor radiation or high plant demand conditions. The balance between supply and demand enabled or not the effect of CO2 enhancement to be expressed. Among the four crops, the light conversion efficiency was significantly modified by CO2 enrichment only in one run. The dry matter increase was not equally partitioned between the organs. It was higher in stem, husks and cob than in leaves and grains. These organs have a morphogenetically limited size (through the number of grains). This controlled the expression of the effect of CO2 enhancement in these runs and explained why the conversion efficiency only increased in one run, which was not morphogenetically limited. These crops proved the interactions between CO2 concentration and the other main climatic factors (temperature and radiation) and the need to know the morphogenesis in order to be able to estimate the effects of CO2 enrichment correctly.

KEYWORDS: ACCUMULATION, CARBON-DIOXIDE ENRICHMENT, DRY-MATTER PRODUCTION, ELEVATED CO2, PLANT-RESPONSES, SOIL-WATER, SOURCE-SINK RELATIONS, USE EFFICIENCY

2071

Runion, G.B., E.A. Curl, H.H. Rogers, P.A. Backman, R. Rodriguezkabana, and B.E. Helms. 1994. Effects of free-air co2 enrichment on microbial-populations in the rhizosphere and phyllosphere of cotton. *Agricultural and Forest Meteorology 70(1-4):117-130.*

Cotton (Gossypium hirsutum L.) plants were exposed to free-air CO2 enriched (FACE = 550 mumol mol-1) or ambient (CONTROL = 370 mumol mol-1) levels of atmospheric CO2 and to wet (100% of evapotranspiration replaced) or dry (67% of ET replaced) soil water content treatments. Foliar, soil and root samples were collected in June and August 1991 to determine the effects of elevated CO2 on selected groups of phyllosphere and rhizosphere microorganisms. Foliage and rhizosphere soil were analyzed for bacteria and/or fungi using dilution plating. Mycorrhizal colonization of cotton roots was assessed. Root-zone soil was analyzed for populations of nematodes, microarthropods and Rhizoctonia using various extraction methods. A dehydrogenase assay for total microbial respiration and a bioassay for cotton root infecting organisms were also conducted using root-zone soil. Populations of fungi on cotton leaves varied, by genera, in response to CO2 enrichment, but none was affected by soil water content treatments; populations of foliar bacteria were not affected by either CO2 or soil water content treatments. In August, higher total numbers of rhizosphere fungi were found under the wet compared with the dry soil water treatment, but differences related to CO2 were not detected. There was a trend for infestation by Rhizoctonia solani to be higher under FACE in the August sample, but the soil bioassay demonstrated no increase in damping-off potential. There was a significant interaction between CO2 concentration and soil water content for populations of saprophagous nematodes; populations were different between the CO2 levels in the dry soil treatment only, with higher numbers under FACE. Microarthropod numbers were low; however, there was a trend for Collembola populations to be higher under FACE in the August sample and more fungi were isolated from Collembola in June. Total microbial activity was higher under FACE at both sample dates. Effects of elevated atmospheric CO2 on plant-microbe interactions could have profound influence on the productivity of agro-ecosystems, and deserve further research.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, COLLEMBOLA, GROWTH, NITROGEN, NODULATION

2072

Runion, G.B., J.A. Entry, S.A. Prior, R.J. Mitchell, and H.H. Rogers. 1999. Tissue chemistry and carbon allocation in seedlings of Pinus palustris subjected to elevated atmospheric CO2 and water stress. *Tree Physiology 19(4-5):329-335.*

Longleaf pine (Pinus palustris Mill.) seedlings were grown in 45-1 pots and exposed to ambient or elevated (365 or 730 mu mol CO2 mol(-1)) CO2 concentration in open-top chambers for 20 months. Two water-stress treatments (target values of -0.5 or - 1.5 MPa xylem pressure potential) were imposed 19 weeks after initiation of the study. At harvest, tissues (needles, stems, taproots, coarse roots, and fine roots) were analyzed for carbon (C), nitrogen (N), nonpolar extractives (fats, waxes, and oils), nonstructural carbohydrates (sugars and starch), structural components (cellulose and lignin), and tannins. The greatest dry weights and lowest N concentrations occurred in tissues of plants grown at elevated CO2 or with adequate water. Although allocation of C fractions among tissues was generally unaffected by treatments, concentrations of the analyzed compounds were influenced by treatments in needles and taproots, but not in stems and lateral roots. Needles and taproots of plants exposed to elevated CO2 had increased concentrations of nonstructural carbohydrates. Among plant tissues, elevated CO2 caused reductions in structural C concentrations and foliar concentrations of fats, waxes and oils.

KEYWORDS: ARMILLARIA-OSTOYAE, CLIMATE CHANGE, DECIDUOUS TREES, DECOMPOSITION RATES, INSECT PERFORMANCE, LEAF LITTER, LONGLEAF PINE, NUTRIENT BALANCE, SOIL CARBON, USE EFFICIENCY

2073

Runion, G.B., R.J. Mitchell, T.H. Green, S.A. Prior, H.H. Rogers, and D.H. Gjerstad. 1999. Longleaf pine photosynthetic response to soil resource availability and elevated atmospheric carbon dioxide. *Journal of Environmental Quality 28(3):880-887.*

Gas exchange responses during a drought cycle were studied in longleaf pine (Pinus palustris Mill.) seedlings after prolonged exposure to varying levels of atmospheric CO2 (approximate to 365 or approximate to 730 mu mol CO2 mol(-1)), soil N (40 or 100 kg N ha(-1) yr(-1)), and water ("adequate" and "stressed"). Elevated atmospheric CO2 concentration increased photosynthesis, tended to decrease stomatal conductance, and increased water-use efficiency (WUE). Although soil resource availability influenced gas exchange measurements, it generally did not affect the magnitude or direction of the response to CO2 concentration. However, significant interactions among treatment variables Here observed for plant xylem pressure potential. In seedlings grown with high N, a positive growth response to elevated atmospheric CO2 increased whole-plant water use resulting in more severe plant water stress, despite increased leaf-level WUE; however, under low N conditions the lark of a growth response to elevated CO2 reduced wholeplant water use, decreased water stress severity, and increased WUE. Photosynthetic response to CO2 was greatest in the high N treatment at the beginning of the drought cycle, but diminished as water stress increased: however, plants grown with low N showed greater photosynthetic responses to CO2 later in the drought cycle. Therefore, plant gas exchange rates interact with growth response in determining the severity of water stress under drought and, thus, the ability of elevated atmospheric CO2 to ameliorate the effects of drought and allow plants to maintain increased rates of photosynthesis mag be influenced bq the availability of other resources, such as N and water.

KEYWORDS: CO2- ENRICHMENT, DROUGHT STRESS, FIELD, GAS-EXCHANGE, GROWTH, LOBLOLLY-PINE, NITROGEN, PLANT-RESPONSES, SEEDLINGS, WATER-USE EFFICIENCY

2074

Running, S.W., D.D. Baldocchi, D.P. Turner, S.T. Gower, P.S. Bakwin, and K.A. Hibbard. 1999. A global terrestrial monitoring network integrating tower fluxes, flask sampling, ecosystem modeling and EOS satellite data. *Remote Sensing of Environment 70(1):108-127.*

Acurrate monitoring of global seals changes in the terrestrial biosphere has become acutely important as the scope of human impacts on biological systems and atmospheric chemistry grows. For example, the Kyoto Protocol of 1997 signals some of the dramatic socioeconomic and political decisions that may lie ahead concerning CO2 emissions and global carbon cycle impacts. These decisions will rely heavily on accurate measures of global biospheric changes (Schimel 1998; IGBP TCWG, 1998). An array of national and international programs have inaugurated global satellite observations, critical field measurements of carbon and water fluxes, and global model development for the purposes of beginning to monitor the biosphere. The detection by these programs of interannual variability of ecosystem fluxes and of longer term trends will permit early indication of fundamental biospheric changes which might otherwise go undetected until major biome conversion begins. This article describes a blueprint for more comprehensive coordination of the various flux measurement and modeling activities into a global terrestrial monitoring network that will have direct relevance to the political decision making of global change. (C) Elsevier Science Inc., 1999.

KEYWORDS: ATMOSPHERIC CARBON-DIOXIDE, CLIMATE CHANGE, CO2, EDDY-CORRELATION, EXCHANGE, FOREST, NET PRIMARY PRODUCTION, SEASONAL-VARIATION, SPATIAL-RESOLUTION, WATER-VAPOR

2075

Rustad, L.E., and I.J. Fernandez. 1998. Experimental soil warming effects on CO2 and CH4 flux from a low elevation spruce-fir forest soil in Maine, USA. *Global Change Biology 4(6):597-605.*

The effect of soil warming on CO2 and CH4 flux from a spruce- fir forest soil was evaluated at the Howland Integrated Forest Study site in Maine, USA from 1993 to 1995. Elevated soil temperatures (similar to 5 degrees C) were maintained during the snow-free season (May November) in replicated 15 x 15-m plots using electric cables buried 1-2 cm below the soil surface; replicated unheated plots served as the control. CO2 evolution from the soil surface and soil air CO2 concentrations both showed clear seasonal trends and significant ($P < 0.0001$) positive exponential relationships with soil temperature. Soil warming caused a 25-40% increase in CO2 flux from the heated plots compared to the controls. No significant differences were observed between heated and control plot soil air CO2 concentrations which we attribute to rapid equilibration With the atmosphere in the O horizon and minimal treatment effects in the B horizon. Methane fluxes were highly variable and showed no consistent trends with treatment.

KEYWORDS: BALANCE, CLIMATE, FLOOR, METHANE, PATTERNS, RESPIRATION, TEMPERATURE, TRACE GAS FLUXES

2076

Rusterholz, H.P., and A. Erhardt. 1998. Effects of elevated CO2 on flowering phenology and nectar production of nectar plants important for butterflies of calcareous grasslands. *Oecologia 113(3):341-349.*

Effects of elevated CO2 on flowering phenology and nectar production were investigated in Trifolium pratense, Lotus corniculatus, Scabiosa columbaria, Centaurea jacea and Betonica officinalis, which are all important nectar plants for butterflies. In glasshouse experiments, juvenile plants were exposed to ambient (350 mu l l(-1)) and elevated (660 mu l l(- 1)) CO2 concentrations for 60-80 days. Elevated CO2 significantly enhanced the development of flower buds in C. jacea. B. officinalis flowered earlier and L. corniculatus produced more flowers under elevated CO2. In contrast, the number of flowers decreased in T. pratense. The amount of nectar per flower was not affected by elevated CO2 in the tested legumes (T. pratense and L. corniculatus), but was significantly reduced (!) in the other forbs. Elevated CO2 did not

significantly affect nectar sugar concentration and composition. However, S. columbaria and C. jacea produced significantly less total sugar under elevated CO2. The nectar amino acid concentration remained unaffected in all investigated plant species, whereas the total of amino acids produced per flower was reduced in all non-legumes. In addition, the amino acid composition changed significantly in all investigated species except for C. jacea. The observed effects are unexpected and are a potential threat to flower visitors such as most butterflies which have no alternative food resources to nectar. Changes in nectar production due to elevated CO2 could also have generally detrimental effects on the interactions of flowers and their pollinators.

KEYWORDS: ADULT DIET, AMINO-ACIDS, ATMOSPHERIC CARBON-DIOXIDE, CHROMATOGRAPHY, ENRICHMENT, GROWTH, LEPIDOPTERA, LIQUIDAMBAR- STYRACIFLUA, PINUS-TAEDA SEEDLINGS, RESPONSES

2077

Ryan, M.G. 1991. Effects of climate change on plant respiration. *Ecological Applications 1(2):157-167.*

Plant respiration is a large, environmentally sensitive component of the ecosystem carbon balance, and net ecosystem carbon flux will change as the balance between photosynthesis and respiration changes. Partitioning respiration into the functional components of construction, maintenance, and ion uptake will aid the estimation of plant respiration for ecosystems. Maintenance respiration is the component most sensitive to changes in temperature, CO2, protein concentration and turnover, water stress, and atmospheric pollutants. For a wide variety of plant tissues, maintenance respiration, corrected for temperature, appears to be linearly related to Kjeldahl nitrogen content of live tissue. Total and maintenance respiration may decline under CO2 enrichment, but the mechanism, independence from changes in protein content, and acclimation are unknown. Response of respiration to temperature can be modelled as a Q10 relationship, if corrections for bias arising from daily and annual temperature amplitude are applied. Occurrence and control of the cyanide- resistant respiratory pathway and acclimation of respiration rates to different climates are poorly understood, but may substantially affect the reliability of model estimates of plant respiration.

KEYWORDS: CO2, CYANIDE- RESISTANT, DARK RESPIRATION, ELEVATED CARBON-DIOXIDE, GRAIN-SORGHUM, GROWTH, LOLIUM-MULTIFLORUM, MAINTENANCE RESPIRATION, ROOT RESPIRATION, WHOLE PLANTS

2078

Rygiewicz, P.T., and C.P. Andersen. 1994. Mycorrhizae alter quality and quantity of carbon allocated below ground. *Nature 369(6475):58-60.*

PLANTS and sails are a critically important element in the global carbon-energy equation. It is estimated that in forest ecosystems over two-thirds of the carbon is contained in soils and peat deposits(1). Despite the importance of forest soils in the global carbon cycle, fluxes of carbon associated with fundamental processes and soil functional groups are inadequately quantified, limiting our understanding of carbon movement and sequestration in soils. We report here the direct measurement of carbon id and through all major pools of a mycorrhizal (fungus-root) coniferous seedling (a complete carbon budget). The mycorrhizal symbiont reduces overall retention of carbon in the plant-fungus symbiosis by increasing carbon in roots and below-ground respiration and reducing its retention and release above ground. Below ground, mycorrhizal plants shifted allocation of carbon to pools that are rapidly turned over, primarily to fine roots and fungal hyphae, and host root and fungal respiration. Mycorrhizae alter the size of below-ground carbon pools, the quality and, therefore, the retention time of carbon below ground. Our data indicate that if elevated atmospheric CO2 and altered climate stressors alter mycorrhizal colonization in forests, the role of forests in sequestering carbon could be altered.

KEYWORDS: CO2, FLOW, HYPHAE, ROOTS, SEEDLINGS, SOIL

2079

Rygiewicz, P.T., M.G. Johnson, L.M. Ganio, D.T. Tingey, and M.J. Storm. 1997. Lifetime and temporal occurrence of ectomycorrhizae on ponderosa pine (Pinus ponderosa Laws) seedlings grown under varied atmospheric CO2 and nitrogen levels. *Plant and Soil 189(2):275-287.*

Climate change (elevated atmospheric CO2, and altered air temperatures, precipitation amounts and seasonal patterns) may affect ecosystem processes by altering carbon allocation in plants, and carbon flux from plants to soil. Mycorrhizal fungi, as carbon sinks, are among the first soil biota to receive carbon from plants, and thereby influence carbon release from plants to soil. One step in this carbon release is via fine root and mycorrhizal turnover. It is necessary to know the lifetime and temporal occurrence of roots and mycorrhizae to determine the capacity of the soil ecosystem to sequester carbon assimilated aboveground. In this study, ponderosa pine (Pinus ponderosa Laws) seedlings were grown under three levels of atmospheric CO2 (ambient, 525 and 700 mu mol CO2 mol(-1)) and three levels of annual nitrogen additions (0,100 and 200 kg N ha(-1)) in open-top chambers. At a two-month frequency during 18 months, we observed ectomycorrhizal root tips observed using minirhizotron tubes and camera. The numbers of new mycorrhizal root tips, the numbers of tips that disappeared between two consecutive recording events, and the standing crop of tips at each event were determined. There were more mycorrhizal tips of all three types seen during the summer compared with other times of the year. When only the standing crop of mycorrhizal tips was considered, effects of the CO2 and N addition treatments on carbon allocation to mycorrhizal tips was weakly evident. However, when the three types of tips were considered collectively, tips numbers flux of carbon through mycorrhizae was greatest in the: (1) high CO2 treatment compared with the other CO2 treatments, and (2) intermediate N addition treatment compared with the other N addition treatments. A survival analysis on the entire 18 month cohort of tips was done to calculate the median lifetime of the mycorrhizal root tips. Average median lifetime of the mycorrhizal tips was 139 days and was not affected by nitrogen and CO2 treatments.

KEYWORDS: CARBON, COMPENSATORY INCREASES, DOUGLAS-FIR STANDS, ELEVATED CO2, FINE ROOTS, FOREST, MYCORRHIZAL COLONIZATION, QUERCUS-ALBA, SEMINAL ROOT-SYSTEM, SOIL RESPIRATION

2080

Ryle, G.J.A., and C.E. Powell. 1992. The influence of elevated co2 and temperature on biomass production of continuously defoliated white clover. *Plant, Cell and Environment 15(5):593-599.*

Clonal plants of white clover (Trifolium repens L.), grown singly in pots of Perlite and solely dependent for nitrogen on root nodule N2 fixation, were maintained in controlled environments which provided four environments: 18/13-degrees-C day/night temperature at 340 and 680-mu-mol mol-1 CO2 and 20.5/15.5-degrees-C day/night temperature at 340 and 680-mu-mol mol-1 CO2. The daylength was 12h and the photon flux density 500+/-25-mu-mol m-2 s-1 (PFD). All plants were defoliated for about 80d, nominally every alternate day, to leave the youngest expanded leaf intact on 50% of stolons, plus expanding leaves (simulated grazing). Elevated CO2 increased the yield of biomass removed at defoliation by a constant 45% during the second 40d of the experiment and by a varying amount in the first half of the experiment. Elevated temperature had little effect on biomass yield. Nitrogen, as a

proportion of the harvested biomass, was only fractionally affected by elevated CO2 or temperature. In contrast, N2 fixation increased in concert with the promoting effect of elevated CO2 on biomass production. The increased yield of biomass harvested in 680 mu- mol mol-1 CO2 was primarily due to the early development and continued maintenance of more stolons. However, the stolons of plants grown in elevated CO2 also developed leaves which were heavier and slightly larger in area than their counterparts in ambient CO2. The conclusion is that, when white clover plants are maintained at constant mass by simulated grazing, they continue to respond to elevated CO2 in terms of a sustained increase in biomass production.

KEYWORDS: CARBON DIOXIDE, ENRICHMENT, ENVIRONMENTS, GROWTH, PHOTOSYNTHESIS, YIELD

2081
Ryle, G.J.A., C.E. Powell, and I.A. Davidson. 1992. Growth of white clover, dependent on n2 fixation, in elevated co2 and temperature. *Annals of Botany 70(3):221-228.*

KEYWORDS: CARBON DIOXIDE, ENRICHMENT, NITROGEN, PHOTOSYNTHESIS, PLANT GROWTH, RESPIRATION, STARCH

2082
Ryle, G.J.A., C.E. Powell, and V. Tewson. 1992. Effect of elevated co2 on the photosynthesis, respiration and growth of perennial ryegrass. *Journal of Experimental Botany 43(251):811-818.*

Single, seed-grown plants of ryegrass (Lolium perenne L. cv. Melle) were grown for 49 d from the early seedling stage in growth cabinets at a day/night temperature of 20/15-degrees-C, with a 12 h photoperiod, and a CO2 concentration of either 340 or 680-mu-l l-1 CO2. Following complete acclimation to the environmental regimes, leaf and whole plant CO2 effluxes and influxes were measured using infra-red gas analysis techniques. Elevated CO2 increased rates of photosynthesis of young, fully expanded leaves by 35-46% and of whole plants by more than 50%. For both leaves and whole plants acclimation to 680-mu-l l-1 CO2 reduced rates of photosynthesis in both CO2 regimes, compared with plants acclimated to 340-mu-l l-1. There was no significant effect of CO2 regime on respiration rates of either leaves or whole plants, although leaves developed in elevated CO2 exhibited generally lower rates than those developed in 340-mu-l l-1 CO2. Initially the seedling plants in elevated CO2 grew faster than their counterparts in 340-mu-l l-1 CO2, but this effect quickly petered out and final plant weights differed by only c. 10%. Since the total area of expanded and unexpanded laminae was unaffected by CO2 regime, specific leaf area was persistently 13-40% lower in elevated CO2 while, similarly, root/shoot ratio was also reduced throughout the experiment. Elevated CO2 reduced tissue nitrogen contents of expanded leaves, but had no effect on the nitrogen contents of unexpanded leaves, sheaths or roots. The lack of a pronounced effect of elevated CO2 on plant growth was primarily due to the fact that CO2 concentration did not influence tiller (branch) numbers. In the absence of an effect on tiller numbers, any possible weight increment was restricted to the c. 2.5 leaves of each tiller. The reason for the lack of an effect on tillering is not known.

KEYWORDS: CARBON-DIOXIDE CONCENTRATION, ENRICHMENT, LIGHT, LOLIUM, NITROGEN, PLANTS, RESPONSES

2083
Ryle, G.J.A., and J. Stanley. 1992. Effect of elevated co2 on stomatal size and distribution in perennial ryegrass. *Annals of Botany 69(6):563-565.*

KEYWORDS: ENRICHMENT, GROWTH

2084
Ryle, G.J.A., J. Woledge, V. Tewson, and C.E. Powell. 1992. Influence of elevated co2 and temperature on the photosynthesis and respiration of white clover dependent on n2 fixation. *Annals of Botany 70(3):213-220.*

KEYWORDS: ATMOSPHERIC CARBON-DIOXIDE, ENRICHMENT, GAS-EXCHANGE, GRASS, LEAVES, NITROGEN, PLANT GROWTH, SHORT- TERM

2085
Sa, T., and D.W. Israel. 1997. Effect of phosphorus deficiency on response of symbiotic N-2 fixation of soybean to atmospheric CO2 enrichment. *Plant Physiology 114(3):484.*

2086
Sa, T.N., and D.W. Israel. 1998. Phosphorus-deficiency effects on response of symbiotic N-2 fixation and carbohydrate status in soybean to atmospheric CO2 enrichment. *Journal of Plant Nutrition 21(10):2207-2218.*

The impact of phosphorus (P) deficiency on response of symbiotic N-2 fixation and carbohydrate accumulation in soybean (Glycine max [L.] Merr.) to atmospheric CO2 enrichment was examined. Plants inoculated with Bradyrhizobium japonicum MN 110 were grown in growth chambers with controlled atmospheres of 400 and 800 mu L CO2 L-1 and supplied either 1.0 mM-P (P- sufficient) or 0.05 mM-P (P-deficient) nitrogen (N)-free nutrient solution. When plants were supplied with sufficient P, CO2 enrichment significantly increased whole plant dry mass (83%), nodule mass (67%), total nitrogenase activity (58%), and N (35%) and P (47%) accumulation at 35 days after transplanting (DAT). Under sufficient P supply, CO2 enrichment significantly increased starch concentrations in nodules compared to the normal atmospheric CO2 treatment. Under normal CO2 levels (400 mu L L-1) nonstructural carbohydrate concentration (starch plus soluble sugar) was significantly higher in leaves of P- deficient plants than in leaves of P-sufficient plants in which nonstructural carbohydrate concentration exhibited a strong diumal pattern. Under deficient P supply whole plant dry mass, symbiotic N-2-fixation parameters, and N and P accumulation were not enhanced by atmospheric CO2 enrichment. Phosphorus deficiency decreased nonstructural carbohydrate accumulation in nodules at the end of a 10-day period in which functional activity was developing by 86% relative to P-sufficient controls. While P deficiency elicited significant increases in the nonstructural carbohydrate concentration in leaves, it caused significant decreases in the nonstructural carbohydrate concentration in nodules over the diurnal cycle from 30 to 31 DAT. Collectively, these results indicate that the lack of a symbiotic N-2-fixation response to atmospheric CO2 enrichment by P-deficient plants may be related to the decreased carbohydrate status of nodules.

KEYWORDS: ELEVATED CARBON-DIOXIDE, GLYCINE-MAX, GROWTH, NUTRITION, PLANTS, SEED YIELD, TOTAL NITROGEN

2087
Saarinen, T. 1998. Internal C : N balance and biomass partitioning of Carex rostrata grown at three levels of nitrogen supply. *Canadian Journal of Botany-Revue Canadienne De Botanique 76(5):762-768.*

The long-term effects of high nitrogen supply on the growth and partitioning of biomass in a common sedge species, Carer rostrata Stokes, were studied in a greenhouse experiment Special attention was paid to free amino acids and soluble sugars, representing biochemically

available fractions of nitrogen and carbon, respectively, in the tissues of Carer. Plants were grown in peat in buckets, and nitrogen was added as ammonium nitrate (2, 5, and 10 g N m(-2) year(-1)) five times during two growing seasons. Changes in biomass allocation patterns became evident towards the end of the second growing season. The biomass of shoots was highest in the high-N treatment, resulting in a high ratio of aboveground to belowground biomass. The high biomass of shoots was due to both the high density of current-year shoots and later senescence in the high-N treatment. No differences were observed in the belowground biomasses. Changes in allocation patterns were accompanied by changes in the soluble fractions of carbon and nitrogen. The concentration of free amino acids (FAA) was significantly higher (both shoots and roots) and the concentration of total nonstructural carbohydrates (TNC) lower (roots only) in the high-N treatment. The concentration of total nitrogen also increased with increasing supply of nitrogen. The results indicate that a high long-term supply of nitrogen may shift the internal carbon to nitrogen balance of Carer towards higher availability of nitrogen. Compared with the carbon to nitrogen ratio, the TNC:FAA ratio seems to be a better indicator of the internal carbon to nitrogen balance. A low TNC:FAA ratio may enhance the allocation of biomass to shoots and also increase the density of shoots.

KEYWORDS: ALLOCATION PATTERNS, ATMOSPHERIC CO2 ENRICHMENT, ELEVATED CO2, FLOATING FENS, FUNCTIONAL EQUILIBRIUM, MINERAL NUTRITION, ROOT, SEASONAL ALLOCATION, SHOOT, VASCULAR PLANTS

2088

Saarnio, S., J. Alm, P.J. Martikainen, and J. Silvola. 1998. Effects of raised CO2 on potential CH4 production and oxidation in, and CH4 emission from, a boreal mire. *Journal of Ecology 86(2):261-268.*

1 In a glasshouse experiment we studied the effect of raised CO2 concentration (720 p.p.m.) on CH4 emission at natural boreal peat temperatures using intact cores of boreal peat with living vascular plants and Sphagnum mosses. After the end of the growing season half of the cores were kept unnaturally warm (17-20 degrees C). The potential for CH4 production and oxidation was measured at the end of the emission experiment. 2 The vascular cores ('Sedge') consisted of a moss layer with sedges, and the moss cores ('Sphagnum') of Sphagnum mosses (some sedge seedlings were removed by cutting). Methane efflux was 6-12 times higher from the Sedge cores than from the Sphagnum cores. The release of CH4 from Sedge cores increased with increasing temperature of the peat and decreased with decreasing temperature. Methane efflux from Sphagnum cores was quite stable independent of the peat temperatures. 3 In both Sedge and Sphagnum samples, CO2 treatment doubled the potential CH4 production but had no effect on the potential CH4 oxidation. A raised concentration of CO2 increased CH4 efflux weakly and only at the highest peat temperatures (17-20 degrees C). 4 The results suggest that in cool regions, such as boreal wetlands, temperature would restrict decomposition of the extra substrates probably derived from enhanced primary production of mire vegetation under raised CO2 concentrations, and would thus retard any consequent increase in CH4 emission.

KEYWORDS: CARBON DIOXIDE, CLIMATIC CHANGE, ENRICHMENT, FEEDBACK, METHANE FLUX, PEATLANDS, PHOTOSYNTHESIS, PLANT-ROOTS, TUNDRA, VEGETATION

2089

Saarnio, S., and J. Silvola. 1999. Effects of increased CO2 and N on CH4 efflux from a boreal mire: a growth chamber experiment. *Oecologia 119(3):349-356.*

Increases in the supply of atmospheric CO2 and N are expected to alter the carbon cycle, including CH4 emissions, in boreal peatlands. These effects were studied in a glasshouse experiment with peat monoliths cored from an oligotrophic pine fen. The cores with living plants were kept in 720 ppm(v) and 360 ppm(v) CO2 atmospheres for about 6 months under imitated natural temperature cycle. Fertilisation with NH4NO3 (3 g m(-2) for 25 weeks) was applied to 18 of the 36 monoliths. The rate of CH4 flux was non-linearly dependent on the number of Eriophorum vaginatum shoots growing in the monoliths, probably due to the gas transport properties of the aerenchyma. The average CH4 efflux rate, standardised by the number of shoots, was increased by a maximum of 10-20% in response to the raised CO2 level. In the raised-NH4NO3 treatment, the increase in CH4 release was lower. The effect of combined CO2 + NH4NO3 on CH4 release was negligible and even lower than in the single treatments. Both potential CH4 production and oxidation rates at 5, 15 and 25 degrees C were higher near the surface than at the bottom of the core. As expected, the rates clearly depended on the incubation temperature, but the different treatments did not cause any consistent differences in either CH4 production or oxidation. The determination of potential CH4 production and oxidation in the laboratory is evidently too crude a method of differentiating substrate-induced differences in CH4 production and oxidation in vivo. These results indicate that an increase in atmospheric CO2 or N supply alone, at least in the short term, slightly enhances CH4 effluxes from boreal peatlands; but together their effect may even be restrictive.

KEYWORDS: BIOMASS ALLOCATION, CARBON DIOXIDE, ELEVATED ATMOSPHERIC CO2, FOREST SOILS, LEAF LITTER, LOLIUM-PERENNE, METHANE EMISSION, NITROGEN-FERTILIZATION, OLIGOTROPHIC PINE FEN, TUSSOCK TUNDRA

2090

Saccardy, K., B. Pineau, O. Roche, and G. Cornic. 1998. Photochemical efficiency of Photosystem II and xanthophyll cycle components in Zea mays leaves exposed to water stress and high light. *Photosynthesis Research 56(1):57-66.*

The effects of two light treatments (photosynthetically active photon flux density of either 650 or 1950 mu mol m(-2) s(-1)) on the photochemical efficiency of Photosystem II (PS II) (measured as variable to maximum fluorescence ratio) and on the xanthophyll cycle components was studied in wilted Zea mays leaves. For comparison, these parameters were followed under the same light conditions in well-hydrated leaves maintained either in normal or CO2-free air. The net CO2 assimilation of dehydrated leaves declined rapidly as their relative water content (RWC) decreased from 100 to 60% while the PS II efficiency measured after a prolonged dark period of 16 h declined only when RWC leaves was lower than 60%. Furthermore, drought caused an increase in the pool size of the xanthophyll cycle pigments and the presence of a sustained elevated level of zeaxanthin and antheraxanthin at the end of the long dark period. The leaf water deficit enhanced the sensitivity of PS II efficiency to light exposure. During illumination, strong inhibition of PS II efficiency and large violaxanthin deepoxidation was observed in wilted leaves even under moderate photon flux density compared to control leaves in the same conditions. After 2 h of darkness following the light treatment, the PS II efficiency that is dependent on the previous PPFD, decreased with leaf water deficit. Moreover, zeaxanthin epoxidation led to an accumulation of antheraxanthin in dehydrated leaves, All these drought effects on PS II efficiency and xanthophyll cycle components were also obtained in well-hydrated leaves by short-term CO2 deprivation during illumination. We conclude that the increased susceptibility of PS II efficiency to light in wilted maize leaves is mainly explained by the decrease of CO2 availability and the resulting low net CO2 assimilation.

KEYWORDS: CHLOROPHYLL-A FLUORESCENCE, COTTON LEAVES, DELTA, DROUGHT STRESS, ENERGY, EXCESS LIGHT, PHOTOSYNTHETIC REACTIONS, QUANTUM YIELD,

VIOLAXANTHIN CYCLE, ZEAXANTHIN EPOXIDATION

2091
Sadowsky, M.J., and M. Schortemeyer. 1997. Soil microbial responses to increased concentrations of atmospheric CO2. *Global Change Biology 3(3):217-224.*

Terrestrial ecosystems respond to an increased concentration of atmospheric CO2. While elevated atmospheric CO2 has been shown to alter plant growth and productivity, it also affects ecosystem structure and function by changing below-ground processes. Knowledge of how soil microbiota respond to elevated atmospheric CO2 is of paramount importance for understanding global carbon and nutrient cycling and for predicting changes at the ecosystem-level. An increase in the atmospheric CO2 concentration not only alters the weight, length, and architecture of plant roots, but also affects the biotic and abiotic environment of the root system. Since the concentration of CO2 in soil is already 10-50 times higher than that in the atmosphere, it is unlikely that increasing atmospheric CO2 will directly influence the rhizosphere. Rather, it is more likely that elevated atmospheric CO2 will affect the microbe-soil- plant root system indirectly by increasing root growth and rhizodeposition rates, and decreasing soil water deficit. Consequently, the increased amounts and altered composition of rhizosphere-released materials will have the potential to alter both population and community structure, and activity of soil- and rhizosphere-associated microorganisms. This occurrence could in turn affect plant health and productivity and plant community structure. This review covers current knowledge about the response of soil microbes to elevated concentrations of atmospheric CO2.

KEYWORDS: BOUTELOUA-GRACILIS, CROP RESPONSES, ELEVATED CARBON-DIOXIDE, ENRICHMENT, LOLIUM-PERENNE, MYCORRHIZAL COLONIZATION, PLANT-RESPONSES, RHIZOSPHERE, SEEDLING GROWTH, TALLGRASS PRAIRIE

2092
Saebo, A., T. Krekling, and M. Appelgren. 1995. Light quality affects photosynthesis and leaf anatomy of birch plantlets in-vitro. *Plant Cell Tissue and Organ Culture 41(2):177-185.*

Cultures in vitro of Betula pendula Roth were subjected to light of different spectral qualities. Photosynthetic capacity was highest when the plantlets were exposed to blue light (max recorded photosynthesis, 82 mu mol CO2 dm(-2) h(-1)) and lowest when irradiated with light high in red and/or far-red wave lengths (max recorded photosynthesis, 40 mu mol CO2 dm(-2) h(- 1)). Highest chlorophyll content (2.2 mg dm(-2) leaf area) was found in cultures irradiated with blue light, which also enhanced the leaf area. Morphometric analysis of light micrographs showed that the epidermal cell areas were largest in plantlets subjected to blue light and smallest in those subjected to red light. Morphometric analysis of electron micrographs of palisade cells, showed that the functional chloroplast area was largest in chloroplasts of leaves subjected to blue light and smallest in those exposed to red light. We suggest that light quality affects photosynthesis both through effects on the composition of the photosynthetic apparatus and on translocation of carbohydrates from chloroplasts.

KEYWORDS: BLUE, CULTURED INVITRO, FLUENCE RATE, GROWTH, PHYTOCHROME, PIGMENTS, RED

2093
Saebo, A., and L.M. Mortensen. 1995. Growth and regrowth of phleum-pratense, lolium-perenne, trifolium-repens and trifolium-pratense at normal and elevated co2 concentration. *Agriculture Ecosystems & Environment 55(1):29-35.*

The effect of elevated CO2 concentration (680 +/- 52 mu mol mol(-1)) on growth of three cultivars of Phleum pratense, two of Lolium perenne and one of Trifolium repens and Trifolium pratense each, was studied during one growth season including three harvests. The study was performed in ten 9 m(2) field chamber units in a cool maritime climate under long days (15-18 h), on the southwest coast of Norway (59 degrees N, 6 degrees E). Tillering in P. pratense and L. perenne was not significantly affected in the first harvest (June/July), but was increased by 30% in the third harvest (September) in response to elevated CO2 concentrations. The plant height was reduced by 16-24% in P. pratense and by 25-29% in L. perenne at high CO2. The dry weight yield of the two grass species was negatively affected by elevated CO2 in the two first harvests, however, no effect was found in the last harvest. The total harvestable dry matter was decreased by 18% in P. pratense and 13% in L. perenne. The dry matter of the stubble was increased at elevated CO2, by 18% in P. pratense and 26% in L. perenne, leaving more of the yield in the meadow after harvest. Raising the CO2 concentration increased the dry weight by 30% in both clover species. The results are discussed in relation to the climatic conditions during the season.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, DIFFERENT IRRADIANCES, ENRICHMENT, NITROGEN, TEMPERATURE, WHEAT, YIELD

2094
Saebo, A., and L.M. Mortensen. 1996. Growth, morphology and yield of wheat, barley and oats grown at elevated atmospheric CO2 concentration in a cool, maritime climate. *Agriculture Ecosystems & Environment 57(1):9-15.*

The effects of elevated CO, concentration on the growth, yield and quality of spring wheat (Triticum aestivum L., cv. 'Sport'), barley(Hordeum vulgare, cv. 'Thule') and oats(Avena sativa, cv. 'Kapp') were studied. The study was performed from 20 April to 24 August in ten field chamber units each of 9 m(2) in a cool (12.6 degrees C) maritime climate under long days (14.6-18.1 h), on the southwest coast of Norway (59 degrees N, 6 degrees E). The total biomass increased at high CO2 concentration, by 11% and 20% in wheat and barley, respectively. The proportion of small grains increased by 6% in wheat and 26% in barley, but the total grain yield was not affected. The weight of chaff increased by 9% and 19% in wheat and barley, respectively. Plant height was significantly reduced during the growing season at elevated CO2, by 8-19% in barley and by 9-25% in oats until 6 July when no significant difference in height was found. After 6 July, barley plants at elevated CO2 were significantly taller than at ambient CO2 concentration and oats were not affected. Elongation in wheat was not affected by CO2 concentration at any time in the growing season. No difference in developmental rate could be detected between plants at normal and elevated CO2 concentrations. The protein content of the grain decreased by 8% in barley, but was not significantly affected in the other species.

KEYWORDS: AIR- TEMPERATURE, AMBIENT, CARBON DIOXIDE, ENRICHMENT, INHIBITION, LEAVES

2095
Saebo, A., and L.M. Mortensen. 1996. The influence of elevated CO2 concentration on growth of seven grasses and one clover species in a cool maritime climate. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science 46(1):49-54.*

The effect of elevated CO2 concentration on the growth of eight common species and cultivars in Norwegian meadows-Festuca pratensis "Salten" and "Fure", Festuca rubra "Koket" and "Leik", Festuca arundinaceae "Vantage" Festuca duruiscula "Barfina", Poa pratensis "Lavang", Agrostis capillar is "Aros", Dactylis glomerata "Apelsvoll", and Trifolium repens "Grasslands Huia"-was studied during 11 weeks

(April 26-early July). The study was performed in ten 9 m(2) large field chamber units in a cool (11.3 degrees C) maritime climate under long days (15.1-18.1 h), on the south-west coast of Norway (59 degrees N, 6 degrees E). The different species responded differently to elevated CO2 with respect to tillering, which was enhanced in A. capillaris (81%), D. glomerata (23%) and F. pratensis (36%), but was not significantly affected in the other species. The sward length was significantly decreased by high CO2 concentration, by 20% in P. pratensis, 36% in A. capillaris, 29% in D. glomerata, 26% in F. duruiscula, 36% in F. pratensis and 16% in F. rubra, but was not affected in F. arundinacea, F. pratensis "Salten" and T. repens. The dry matter was decreased at elevated CO2 concentration in A. capillaris (14%), increased in F. rubra (10%) and not significantly affected in the other plants. The results are discussed in relation to climate and interspecific responses.

KEYWORDS: AIR- TEMPERATURE, AMBIENT, ATMOSPHERIC CO2, CARBON DIOXIDE, ENRICHMENT, NITROGEN, ORANGE TREE LEAVES, PHOSPHORUS, WHEAT, YIELD

2096

Saebo, A., and L.M. Mortensen. 1998. Influence of elevated atmospheric CO2 concentration on common weeds in Scandinavian agriculture. *Acta Agriculturae Scandinavica Section B-Soil and Plant Science 48(3):138-143.*

This study investigated the influence of elevated CO, on three perennial weed species (Achillea millefolium, Leontodon autumnalis and Rumex acetosa) and seven annual species (Chenopodium album, Matricaria matricarioides, Poa annua, Polygonum persicaria, Senecio vulgaris, Spergula arvensis and Stellaria media). The study was carried out during the period 3 May to 5 August in ten field chamber units of 9 m(2) in a cool (12.6 degrees C) maritime climate under long days (15.8-18.1 h day(-1)) on the south-west coast of Norway (59 degrees N, 6 degrees E). Dry weights of the seven annual species were not significantly affected by the CO2 concentration. Of the three perennial species, L. autumnalis increased in dry weight by 27% and A. millefolium by 19% at elevated compared with ambient CO2 concentration. Plant height increased by 8% in L. autumnalis and decreased by 12 and 10% in M. matricarioides and P. annua, respectively. Leaf size increased by 32% and specific leaf area decreased by 23% in P. persicaria at elevated CO2, while the other species were unaffected. The results are discussed in relation to competition between species and the influence of climate on the CO2 responses.

KEYWORDS: AIR- TEMPERATURE, AMBIENT, CARBON DIOXIDE, COOL, ENRICHMENT, GROWTH, MARITIME CLIMATE, NITROGEN, WHEAT, YIELD

2097

Saetersdal, M., and H.J.B. Birks. 1997. A comparative ecological study of Norwegian mountain plants in relation to possible future climatic change. *Journal of Biogeography 24(2):127-152.*

Mountain plants constitute an important part of the Norwegian flora. They are also believed to be the plant group in Norway most threatened by the expected climatic warming due to an enhanced greenhouse effect in the near future. In this study the distributions of 107 mountain Norwegian vascular plants were modelled in relation to present-day climate using Gaussian legit regression. Most species are found to have a surprisingly broad amplitude to mean July and January temperatures, suggesting that a 2 degrees C increase in summer temperature and 4 degrees C increase in winter temperature (as expected with a 2 x CO2 increase) may not have a dramatic direct effect on most of the species investigated. A comparative study between estimated July and January temperature optima and tolerances and other ecological attributes such as habitat characteristics, dispersal mechanisms, range sizes and other climatic optima and tolerances was done using multivariate analysis. The results suggest that species most vulnerable to climatic warming, namely the species with narrow July and January temperature tolerances, are characterized by small range sizes and small population sizes, i.e. they are nationally rare species. Furthermore, these vulnerable species are found in all habitats along the major moisture gradient in alpine vegetation. A classification of the species into Rabinowitz's seven forms of rarity confirms that the species most vulnerable to climatic warming are characterized by being habitat specialists with a small geographic range size.

KEYWORDS: ABUNDANCE, ENVIRONMENTAL-CHANGE, FALLOPIA-JAPONICA, GRADIENT ANALYSIS, GROWTH, MODEL, NUMERICAL- ANALYSIS, PATTERNS, REPRODUCTIVE DEVELOPMENT, RESPONSES

2098

Sage, R.F. 1990. A model describing the regulation of ribulose-1,5-bisphosphate carboxylase, electron-transport, and triose phosphate use in response to light-intensity and CO2 in C3 plants. *Plant Physiology 94(4):1728-1734.*

A model of the regulation of the activity of ribulose-1,5-bis- phosphate carboxylase, electron transport, and the rate of orthophosphate regeneration by starch and sucrose synthesis in response to changes in light intensity and partial pressures of CO2 and O2 is presented. The key assumption behind the model is that nonlimiting processes of photosynthesis are regulated to balance the capacity of limiting processes. Thus, at CO2 partial pressures below ambient, when a limitation on photosynthesis by the capacity of rubisco is postulated, the activities of electron transport and phosphate regeneration are down-regulated in order that the rate of RuBP regeneration matches the rate of RuBP consumption by rubisco. Similarly, at subsaturating light intensity or elevated CO2, when electron transport or Pi regeneration may limit photosynthesis, the activity of rubisco is downregulated to balance the limitation in the rate of RuBP regeneration. Comparisons with published data demonstrate a general consistency between modelled predictions and measured results.

KEYWORDS: ELEVATED CO2, GAS-EXCHANGE, INTACT LEAVES, INVIVO, OXYGENASE, PHASEOLUS-VULGARIS L, PHOTOSYNTHESIS, RIBULOSE BISPHOSPHATE CARBOXYLASE, TEMPERATURE, WHEAT SEEDLINGS

2099

Sage, R.F. 1994. Acclimation of photosynthesis to increasing atmospheric co2 - the gas-exchange perspective. *Photosynthesis Research 39(3):351-368.*

The nature of photosynthetic acclimation to elevated CO2 is evaluated from the results of over 40 studies focusing on the effect of long-term CO2 enrichment on the short-term response of photosynthesis to intercellular CO2 (the A/C-i response). The effect of CO2 enrichment on the A/C-i response was dependent on growth conditions, with plants grown in small pots (<5 L) or low nutrients usually exhibiting a reduction of A at a given C-i, while plants grown without nutrient deficiency in large pots or in the field tended to exhibit either little reduction or an enhancement of A at a given C-i following a doubling or tripling of atmospheric CO2 during growth. Using theoretical interpretations of A/C-i curves to assess acclimation, it was found that when pot size or nutrient deficiency was not a factor, changes in the shape of A/C-i curves which are indicative of a reallocation of resources within the photosynthetic apparatus typically were not observed. Long-term CO2 enrichment usually had little effect or increased the value of A at all C-i. However, a minority of species grown at elevated CO2 exhibited gas exchange responses indicative of a reduced amount of

Rubisco and an enhanced capacity to metabolize photosynthetic products. This type of response was considered beneficial because it enhanced both photosynthetic capacity at high CO2 and reduced resource investment in excessive Rubisco capacity. The ratio of intercellular to ambient CO2 (the C-i/C-a ratio) was used to evaluate stomatal acclimation. Except under water and humidity stress, C-i/C-a, exhibited no consistent change in a variety of C-3 species, indicating no stomatal acclimation. Under drought or humidity stress, C-i/C-a declined in high-CO2 grown plants, indicating stomata will become more conservative during stress episodes in future high CO2 environments.

KEYWORDS: C-3 PLANTS, CHENOPODIUM-ALBUM L, ELECTRON-TRANSPORT, ELEVATED CARBON-DIOXIDE, INTACT LEAVES, LONG-TERM EXPOSURE, PHASEOLUS-VULGARIS L, RIBULOSE-1;5- BISPHOSPHATE CARBOXYLASE ACTIVITY, STOMATAL CONDUCTANCE, ULTRAVIOLET-B RADIATION

2100

Sage, R.F. 1995. Was low atmospheric co2 during the pleistocene a limiting factor for the origin of agriculture. *Global Change Biology 1(2):93-106.*

Agriculture originated independently in many distinct regions at approximately the same time in human history. This synchrony in agricultural origins indicates that a global factor may have controlled the timing of the transition from foraging to food- producing economies. The global factor may have been a rise in atmospheric CO:! from below 200 to near 270 mu mol mol(-1) which occurred between 15,000 and 12,000 years ago. Atmospheric CO2 directly affects photosynthesis and plant productivity, with the largest proportional responses occurring below the current level of 350 mu mol mol(-1). In the late Pleistocene, CO2 levels near 200 mu mol mol(-1) may have been too low to support the level of productivity required for successful establishment of agriculture. Recent studies demonstrate that atmospheric CO2 increase from 200 to 270 mu mol mol(-1) stimulates photosynthesis and biomass productivity of C-3 plants by 25% to 50%, and greatly increases the performance of C-3 plants relative to weedy C-4 competitors. Rising CO2 also stimulates biological nitrogen fixation and enhances the capacity of plants to obtain limiting resources such as water and mineral nutrients. These results indicate that increases in productivity following the late Pleistocene rise in CO2 may have been substantial enough to have affected human subsistence patterns in ways that promoted the development of agriculture. Increasing CO2 may have simply removed a productivity barrier to successful domestication and cultivation of plants. Through effects on ecosystem productivity rising CO2 may also have been a catalyst for agricultural origins by promoting population growth, sedentism, and novel social relationships that in turn led to domestication and cultivation of preferred plant resources.

KEYWORDS: CLIMATE CHANGE, ELEVATED CARBON-DIOXIDE, GROWTH-RESPONSE, MINERAL NUTRITION, NITROGEN-FIXATION, PHOTOSYNTHETIC ACCLIMATION, PLANTS, RISING CO2, SOIL ORGANIC MATTER, WATER RELATIONS

2101

Sage, R.F., J. Santrucek, and D.J. Grise. 1995. Temperature effects on the photosynthetic response of C-3 plants to long-term CO2 enrichment. *Vegetatio 121(1-2):67-77.*

To assess the long-term effect of increased CO2 and temperature on plants possessing the C-3 photosynthetic pathway, Chenopodium album plants were grown at one of three treatment conditions: (1) 23 degrees C mean day temperature and a mean ambient partial pressure of CO2 equal to 350 mu bar; (2) 34 degrees C and 350 mu bar CO2; and (3) 34 degrees C and 750 mu bar CO2. No effect of the growth treatments was observed on the CO2 response of photosynthesis, the temperature response of photosynthesis, the content of Ribulose-1,5-bisphosphate carboxylase (Rubisco), or the activity of whole chain electron transport when measurements were made under identical conditions. This indicated a lack of photosynthetic acclimation in C. album to the range of temperature and CO2 used in the growth treatments. Plants from every treatment exhibited similar interactions between temperature and CO2 on photosynthetic activity. At low CO2 (< 300 mu bar), an increase in temperature from 25 to 35 degrees C was inhibitory for photosynthesis, while at elevated CO2 (> 400 mu bar), the same increase in temperature enhanced photosynthesis by up to 40%. In turn, the stimulation of photosynthesis by CO2 enrichment increased as temperature increased. Rubisco capacity was the primary limitation on photosynthetic activity at low CO2 (195 mu bar). As a consequence, the temperature response of A was relatively flat, reflecting a low temperature response of Rubisco at CO2 levels below its k(m) for CO2. At elevated CO2 (750 mu bar), the temperature response of electron transport appeared to control the temperature dependency of photosynthesis above 18 degrees C. These results indicate that increasing CO2 and temperature could substantially enhance the carbon gain potential in tropical and subtropical habitats, unless feedbacks at the whole plant or ecosystem level limit the long-term response of photosynthesis to an increase in CO2 and temperature.

KEYWORDS: ACCLIMATION, ATMOSPHERIC CO2, CHENOPODIUM-ALBUM L, ELEVATED CARBON-DIOXIDE, GAS-EXCHANGE, LIGHT-INTENSITY, NERIUM-OLEANDER, PHASEOLUS-VULGARIS L, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, SOURCE-SINK RELATIONS

2102

Sage, R.F., B. Schappi, and C. Korner. 1997. Effect of atmospheric CO2 enrichment on Rubisco content in herbaceous species from high and low altitude. *Acta Oecologica-International Journal of Ecology 18(3):183-192.*

Atmospheric CO2 enrichment reduces Rubisco content in many species grown in controlled environments; however, relatively few studies have examined CO2 effects on Rubisco content of plants grown in their natural habitat. We examined the response of Rubisco content to atmospheric CO2 enrichment (600-680 mu mol mol-l in place of ppm) in 5 herbaceous species growing in a low altitude grassland (550 m) near Basel, Switzerland, and 3 herbaceous species from Swiss alpine grassland at 2 470 m. At low elevation, the dominant grass Bromus erectus and the subdominant dicot Sanquisorba miller exhibited 20% to 25% reduction of Rubisco content following high CO2 exposure; no CO2 effect was observed in the subdominants Carex flacca, Lotus corniculatus and Trifolium repens. At the Alpine site, the subdominant grass Pea alpina maintained 27% less Rubisco content when grown at high CO2 while the co-dominant forb Leontodon helveticus had 19% less Rubisco in high CO2: Rubisco content was unaffected in the tundra dominant Carer curvula. Because the degree of Rubisco modulation was similar between high and low elevation sites, it does not appear that differences in local partial pressure of CO2 (altitude) or differences in stress in general induce different patterns of modulation of photosynthetic capacity in response to high CO2. In addition, the degree of Rubisco reduction (<30%) was less than might be indicated by the low biomass response to CO2 enrichment previously observed al these sites. Thus, plants in Swiss lowland and alpine grassland appear to main tain greater Rubisco concentration and photosynthetic capacity than whale plants can effectively exploit in terms of harvestable biomass.

KEYWORDS: ALPINE GRASSLAND, C-3, ELEVATED CO2, EXPRESSION, GROWTH, LEAVES, LIGHT-DEPENDENT REGULATION, PHOTOSYNTHETIC ACCLIMATION, PLANTS

2103

Sage, R.F., T.D. Sharkey, and J.R. Seemann. 1990. Regulation of ribulose-1,5-bisphosphate carboxylase activity in response to light-intensity and CO2 in the C3 annuals Chenopodium album L and Phaseolus vulgaris L. *Plant Physiology 94(4):1735-1742.*

The light and CO2 response of (a) photosynthesis, (b) the activation state and total catalytic efficiency (K(cata)) of ribulose-1,5-bisphosphate carboxylase (rubisco), and (c) the pool sizes of ribulose 1,5-bisphosphate, (RuBP), ATP, and ADP were studied in the C3 annuals Chenopodium album and Phaseolus vulgaris at 25-degrees-C. The initial slope of the photosynthetic CO2 response curve was dependent on light intensity at reduced light levels only (less than 450 micromoles per square meter per second in C. album and below 200 micromoles per square meter per second in P. vulgaris). Modeled simulations indicated that the initial slope of the CO2 response of photosynthesis exhibited light dependency when the rate of RuBP regeneration limited photosynthesis, but not when rubisco capacity limited photosynthesis. Measured observations closely matched modeled simulations. The activation state of rubisco was measured at three light intensities in C. album (1750, 550, and 150 micromoles per square meter per second) and at intercellular CO2 partial pressures (C(i)) between the CO2 compensation point and 500 microbars. Above a C(i) of 120 microbars, the activation state of rubisco was light dependent. At light intensities of 550 and 1750 micromoles per square meter per second, it was also dependent on C(i), decreasing as the C(i) was elevated above 120 microbars at 550 micromoles per square meter per second and above 300 microbars at 1750 micromoles per square meter per second. The pool size of RuBP was independent of C(i) only under conditions when the activation state of rubisco was dependent on C(i). Otherwise, RuBP pool sizes increases as C(i) was reduced. ATP pools in C. album tended to increase as C(i) was reduced. In P. vulgaris, decreasing C(i) at a subsaturating light intensity of 190 micromoles per square meter per second increased the activation state of rubisco but had little effect on the K(cat). These results support modelled simulations of the rubisco response to light and CO2, where rubisco is assumed to be down-regulated when photosynthesis is limited by the rate of RuBP regeneration.

KEYWORDS: ABSCISIC- ACID, CHLOROPLAST PROTEIN, GAS-EXCHANGE, INTACT LEAVES, OXYGENASE, PHOTOSYNTHESIS, POOL SIZES, RIBULOSE BISPHOSPHATE CARBOXYLASE, RUBISCO ACTIVASE, WHEAT SEEDLINGS

2104

Sagi, M., A. Dovrat, T. Kipnis, and H. Lips. 1998. Nitrate reductase, phosphoenolpyruvate carboxylase, and glutamine synthetase in annual ryegrass as affected by salinity and nitrogen. *Journal of Plant Nutrition 21(4):707-723.*

The concentration of organic acids, organic nitrogen (N), nitrate (NO3), and total cations increased in annual ryegrass (Lolium multiflorum Lam.) with salinity and N concentration in the growth medium. Increasing salinity and N in the growth medium induced changes in the level of key enzymes of N assimilation and organic acids: nitrate reductase (NR, EC 1.6.6.1), phosphoenolpyruvate carboxylase (PEPc, EC 4.1.1.31), and glutamine synthetase (GS, EC 6.3.1.2). Plants grown in pots filled with sand were irrigated with nutrient solutions with an electroconductivity of 2 or 11.2 dS m(-1) and N applied as ammonium nitrate (NH4NO3), sodium nitrate (NaNO3), or ammonium applied as ammonium nitrate (NH4NO3), sodium nitrate (NaNO3), or ammonium (NH4) as ammonium sulfate [(NH4)(2)SO4] at concentrations of 0.5, 4.5 or 9.0 mM. Nitrate reductase, PEPc, and GS increased with salinity and N level. Shoot NR was highest in the presence of NH4NO3 irrespective of salinity level, while root NR activity responded best to NO3. Enhancement of PEPc activity in both shoots and roots was highest with NH4NO3 and lowest with NH4. Nitrogen source had no significant effect on GS activity in shoots or roots of ryegrass. Shoot NR activity increased with NO3 concentration in the tissue, as calculated from repression coefficients. The PEPc activity correlated positively with total cations and NO3 concentrations in the plants, irrespective of the salinity level, suggesting that the increase in total cations and NO3 induced by salinity may have triggered the changes in enzyme activities. The concentration of organic acids in both shoots and roots correlated positively with PEPc activity irrespectively of the salinity level. The PEPc activity was higher in roots than in shoots, while organic acid concentration was higher in shoots. These results suggest that a significant part of the organic acids produced in the roots were used as carbon skeleton for transamination reactions. The increased activity of NR, PEPc, and GS in roots may constitute part of an adaptation strategy of the plant to increasing salinity in the medium. These enzymes have an important role in the metabolism of amino acids and the synthesis of organic N in annual ryegrass irrigated with saline water, and boosting them with suitable N fertilizers could increase the nutritional value and protein content of the crop.

KEYWORDS: ASSIMILATION, CARBON, ENRICHED RHIZOSPHERE CO2, GROWTH, HIGHER-PLANTS, METABOLISM, NUTRITION, SEEDLINGS, STRESS, TOMATO

2105

Saito, M., T. Homma, Y. Nemoto, and H. Matsuoka. 1993. Intracellular potential change of tradescantia-virginiana L leaf in response to co2 stress. *Bioelectrochemistry and Bioenergetics 32(2):133-143.*

The response of a Tradescantia virginiana L. leaf to CO2 stress was measured using a double-barrelled microelectrode (a potential recording electrode and an electrode carrying Lucifer yellow CH dye (LY)). After potential measurement, LY was allowed to diffuse out of the microelectrode by iontophoresis. The position of electrode tip was ascertained from the pattern of LY diffusion. The intracellular potential changed markedly in response to CO2 stress. The most typical response pattern obtained during CO2 exposure (ON response) was two-phase, initially changing in the positive direction and then in the negative direction. During the ON response, marked efflux of K+ and slight influx of Cl- occurred initially, followed by efflux of Cl- and influx of H+. On cessation of CO2 exposure, the potential showed a similar two-phase pattern (OFF response) but the ion fluxes reversed. Therefore the effect Of CO2 exposure is not just decrease in intracellular pH owing to dissolution Of CO2.

KEYWORDS: ELEVATED CO2, LEAVES, PH MICRO-ELECTRODES, PHOTOSYNTHESIS, PLANT-CELLS

2106

Sala, A., and J.D. Tenhunen. 1996. Simulations of canopy net photosynthesis and transpiration in Quercus ilex L under the influence of seasonal drought. *Agricultural and Forest Meteorology 78(3-4):203-222.*

A mechanistically based C-3 leaf photosynthesis model combined with an empirical stomatal model and a canopy model of light interception and microclimate was used to simulate Quercus ilex canopy net photosynthesis and transpiration at l'Avic watershed (NE Spain). The model takes into account the sun-shade leaf differentiation of photosynthetic characteristics as affected by depth within the canopy. Based on field studies, simulations were carried out for two locations within the watershed along a gradient in elevation, microclimate and forest structure. Effective predictions of diurnal and seasonal courses of stomatal conductance of sun and shade leaves for different days during the year were obtained by changing a single model variable termed g(F). The value of g(F) determined from least squares of observed vs. simulated time courses was linearly related to pre-dawn xylem water

potential over critical ranges of the response curve. Response to g(F) in the model may to a great extent be thought of as the integrated expression of canopy response to root system generated signals or control mechanisms. For development of predictive capability, g(F) is extremely useful because it allows seasonal assessments of water use and carbon dioxide uptake with differing patterns in water availability. Based on simulated responses on representative clear, overcast and variable days throughout the year, only small differences in annual totals for net photosynthesis and transpiration were found between the two sites, despite large differences in soil drying. Annual estimates of canopy water loss were in close agreement with independent estimates of evapotranspiration using the hydrological input/output method.

KEYWORDS: CAPACITY, CARBON GAIN, EFFICIENCY, ELEVATED CO2, EXCHANGE, FOREST, NITROGEN, OAK, STOMATAL CONDUCTANCE, WATER-USE

2107

Saleska, S.R., J. Harte, and M.S. Torn. 1999. The effect of experimental ecosystem warming on CO2 fluxes in a montane meadow. *Global Change Biology 5(2):125-141.*

Climatic change is predicted to alter rates of soil respiration and assimilation of carbon by plants. Net loss of carbon from ecosystems would form a positive feedback enhancing anthropogenic global warming. We tested the effect of increased heat input, one of the most certain impacts of global warming, on net ecosystem carbon exchange in a Rocky Mountain montane meadow. Overhead heaters were used to increase the radiative heat flux into plots spanning a moisture and vegetation gradient. We measured net whole-ecosystem CO2 fluxes using a closed-path chamber system, relatively nondisturbing bases, and a simple model to compensate for both slow chamber leaks and the CO2 concentration-dependence of photosynthetic uptake, in 1993 and 1994. In 1994, we also measured soil respiration separately. The heating treatment altered the timing and magnitude of net carbon fluxes into the dry zone of the plots in 1993 (reducing uptake by approximate to 100 g carbon m(-2)), but had an undetectable effect on carbon fluxes into the moist zone. During a strong drought year (1994), heating altered the timing, but did not significantly alter the cumulative magnitude, of net carbon uptake in the dry zone. Soil respiration measurements showed that when differences were detected in dry zone carbon Fluxes, they were caused by changes in carbon input from photosynthesis, not by temperature-driven changes in carbon output from soil respiration. When differences were detected in dry-zone carbon fluxes, they were caused by changes in carbon input from photosynthesis, not by a temperature-driven changes in carbon output from soil respiration. Regression analysis suggested that the reduction in carbon inputs from plants was due to a combination of two soil moisture effects: a direct physiological response to decreased soil moisture, and a shift in plant community composition from high-productivity species to low-productivity species that are more drought tolerant. These results partially support predictions that warming may cause net carbon losses from some terrestrial ecosystems. They also suggest, however, that changes in soil moisture caused by global warming may be as important in driving ecosystem response as the direct effects of increased soil temperature.

KEYWORDS: ATMOSPHERIC CARBON-DIOXIDE, CLIMATIC CHANGE, FEEDBACKS, MANIPULATION, PLANT-RESPONSES, SOIL MICROCLIMATE, STORAGE, TEMPERATURE, TRACE GAS FLUXES, VEGETATION

2108

Sallanon, H., B. Dimon, P. Carrier, and P. Chagvardieff. 1995. Effects of co2 concentration and irradiance on growth and photosynthesis of juglans-regia plantlets grown in-vitro. *Photosynthetica 31(2):241-249.*

Walnut (Juglans regia L.) plantlets were incubated during micropropagation in standard vessels (quasi confined vessels) or in aerated vessels flushed with 360 or 20 000 cm(3)(CO2) m(- 3) under irradiances of 70 (LI) and 250 (HI) mu mol m(-2) s(- 1). Plantlet morphology was strongly affected by the environment: leaf surface was increased, but shoot elongation and number of stems were reduced after increasing the irradiance of culture. Gross photosynthesis (P-G) capacity measured by using the O-18(2) isotope and mass-spectrometry techniques was increased by increasing photosynthetic photon flux (PPF) and CO2 concentration. Plantlets exhibited a potential for photorespiratory activity and Mehler-type reaction and a high rate of mitochondrial respiration in all vessel types and irradiances. When a long-term HI was applied, gas exchange rates (P-G and O-2 uptake) were reduced in most of the vessel and PPF conditions, except in quasi confined vessels. Under all the growth conditions, net photosynthetic rate (P-N) was zero or slightly positive and the dry matter accumulation was very similar. Changes in O-2 exchange, growth rate or enzyme activities linked to carbon fixation that were induced by changes in PFD and CO2 concentration showed that the photosynthetic characteristics of plantlets were typical for hetero-mixotrophic tissues.

KEYWORDS: ENRICHMENT, FIXATION, INVITRO, LEAVES, LIGHT, O2, RESPIRATION

2109

Sallanon, H., H. Isaka, B. Dimon, C. Ravel, and P. Chagvardieff. 1997. CO2 exchanges and nutrient uptake during multiplication and rooting of micropropagated Juglans regia plantlets. *Plant Science 124(1):107-116.*

CO2 gas exchanges in light and dark, PEPC and Rubisco activities and consumption of sugar and mineral nutrients (K+, Ca2+ Mg2+: NH4+, NO3-, PO43-, SO42-) were measured during multiplication and rooting stages of in vitro-cultivated Juglans regia. CO2 gas exchanges in light and dark, and PEPC and Rubisco activities varied with plantlet age during a growth cycle. They were higher during the first part of the exponential stage of growth (defined in terms of dry weight increase). Respiratory gas exchanges were always higher than photosynthetic ones. The differences between the two stages of growth were reflected in respiration/photosynthesis and total Rubisco activity/initial Rubisco activity ratios, which were higher in the rooting than in the multiplication stage. This work underlines the need to consider the wide variations in photosynthetic and respiratory gas exchanges related to the plantlet development stage. Mineral absorption also displayed variations, both in the quantity and selectivity of the inorganic nutrients supplied. During the multiplication stage, fast exhaustion of PO43- and NH4(+) occurred, whereas depletion of Ca2+, NH4+, PO43- and SO42- were observed throughout the rooting stage. The inhibition of photosynthetic activity may be linked to the presence of sugar in the medium and also to ion deficiencies during the multiplication stage. Hence, this work also highlights the importance of mineral elements, suggesting a need to review nutrient medium compositions. (C) 1997 Elsevier Science Ireland Ltd.

KEYWORDS: AERATION, ANATOMY, CULTURE, ENRICHMENT, GROWTH, INVITRO, PHOTOSYNTHESIS

2110

Salt, D.T., G.L. Brooks, and J.B. Whittaker. 1995. Elevated carbon-dioxide affects leaf-miner performance and plant-growth in docks (rumex spp). *Global Change Biology 1(2):153-156.*

Exposure of R. crispus and R. obtusifolius to elevated CO2 (600 ppm) resulted in an increased C:N ratio of leaf tissue and greater leaf areas. Larvae of P. nigritarsis mining leaves of X. obtusifolius during exposure produced significantly bigger mines in elevated than in ambient (350

ppm) conditions. There were no significant treatment effects on pupal weight although in both host species mean weight was greater in ambient than in elevated conditions. These results are consistent with the hypothesis that insect herbivores compensate for increased C:N ratios by increased food consumption This response by herbivores may partially offset predicted increases in plant biomass in a future high CO2 environment.

KEYWORDS: CO2, INSECTS, YIELD

2111
Salt, D.T., P. Fenwick, and J.B. Whittaker. 1996. Interspecific herbivore interactions in a high CO2 environment: Root and shoot aphids feeding on Cardamine. *Oikos 77(2):326-330.*

This study investigated the effects of elevated CO2 on populations of root and/or shoot aphids and their effects on partitioning in Cardamine pratensis. Total plant biomass in elevated (approximate to 600 ppm) CO2 of uninfested Cardamine plants was 52% higher than in ambient (approximate to 350 ppm) concentrations but CO2 effects were not statistically significant. In elevated CO2, feeding by shoot aphids (Aphis fabae fabae) alone and in combination with root aphids (Pemphigus populitransversus), and root aphids alone had no significant effect on plant biomass. No significant effects of elevated CO2 were detected on population size of the shoot or root-feeding species. Interspecific effects were detected between the root and shoot species. Root aphid populations were significantly smaller in the presence of shoot aphids on the same plants. In this system plant growth was unaffected by an elevated CO2 environment. Plant species which are more sensitive to elevated CO2 may show a modified response to herbivore pressure in a future atmospheric environment.

KEYWORDS: COMPETITION, FIELD, GROWTH, HOMOPTERA, INSECT HERBIVORES, PERFORMANCE, PLANT-MEDIATED INTERACTIONS, QUALITY, RESISTANCE, STRESS

2112
Samarakoon, A.B., and R.M. Gifford. 1995. Soil water content under plants at high CO2 concentration and interactions with the direct CO2 effects: A species comparison. *Journal of Biogeography 22(2-3):193-202.*

Wheat, maize and cotton, grown as spaced plants in large pots of soil, differed in the way high (2 X ambient) CO2 concentration affected the time-course of soil water use. For wheat, the tendency to conserve water owing to reduction in stomatal conductance in high CO2 was largely offset by the stimulation of leaf area development as the soil column dried. However, when the soil was maintained continuously wet, soil water conservation occurred because in the absence of water stress high CO2 did not maintain a greater leaf area. For maize, which has little or no photosynthetic response to CO2 concentrations above ambient but a strong stomatal response, water was conserved and the soil profile dried more slowly. Maize leaf area and dry matter growth increased in response to damper soil under high CO2, despite no growth response to CO2 in the absence of water stress. For cotton, which has a strong photosynthetic but weak stomatal response to CO2, the soil column dried faster under high CO2. Despite this drier soil, cotton still showed the greatest response to high CO2 of leaf area and dry matter growth of the three species compared. Under wet soil conditions, cotton exhibited a very large leaf area response to CO2 leading to much greater water use per plant. This contrasts with both wheat and maize which conserved water at high CO2 when wet. Despite these contrasting transpiration and growth responses, all three species exhibited a relatively similar increase in water use efficiency under high CO2 for both wet and dry conditions. It is concluded that the secondary effect of high CO2 on soil water content exerts a strong confounding influence on growth responses to CO2. In the longer term, the changed soil water status would influence hydrology, soil microbiology, nutrient relations and species composition. From indirect evidence it is proposed that the relative enhancement of growth owing to CO2 enrichment is greater under drought conditions than in wet soil because of the effect of water deficit on the intercellular CO2 concentration in the leaf, C-i. If water deficits cause C-i/C-a to decline then photosynthesis is operating in a more CO2-sensitive region of the CO2 response curve.

KEYWORDS: CARBON DIOXIDE, COTTON, FIELD, GROWTH, LEAF, PHOTOSYNTHESIS, STOMATAL CONDUCTANCE, TRANSPIRATION, WHEAT, YIELD

2113
Samarakoon, A.B., and R.M. Gifford. 1996. Elevated CO2 effects on water use and growth of maize in wet and drying soil (vol 23, pg 53, 1996). *Australian Journal of Plant Physiology 23(3):401.*

2114
Samarakoon, A.B., and R.M. Gifford. 1996. Elevated CO2 effects on water use and growth of maize in wet and drying soil. *Australian Journal of Plant Physiology 23(1):53-62.*

It is unclear from the literature as to whether growth of C-4 species is responsive to elevated atmospheric CO2 concentration. Reports vary between no response to strong response. To explore the origin of this discrepancy, spaced plants of maize (Zea mays) were grown at atmospheric CO2 concentrations of 362 or 717 mu L L(-1) under continuously wet or drying soil regimes. The aims were to evaluate the comparative growth promotion from elevated CO2 in a C-4 plant under the two contrasting water regimes and the causes of any such promotion, and also how water-use efficiency (WUE) is influenced by high CO2 under the two water regimes. In wet soil, transpiration rate was reduced on average by 29% at high CO2 but neither total dry matter nor plant height was significantly affected by CO2 level. Leaf area was not influenced significantly, so daily water use per plant was 25% lower and WUE was increased entirely due to reduced water use at high CO2. In soil that was drying from field capacity, plants in high CO2 used about 30% less water than those in ambient CO2 while the soil was still wet. This resulted in higher soil water content at high CO2. Plant growth showed a marked response, accumulating 35% more leaf area and 50% more dry matter. Young internodes elongated up to 170% more, giving taller plants. The growth enhancement was largely due to higher average net assimilation rate indicating that C-4 photosynthesis responded to elevated CO2 during drought. In drying soil the increase in WUE was due to both increased dry matter and reduced water use, the contribution from each depending on the stage of soil drying. We hypothesise therefore that literature examples where maize growth responded to elevated CO2 may have involved (possibly unrecognised) minor water deficits.

KEYWORDS: AMBIENT, ATMOSPHERIC CO2, CARBON DIOXIDE, COMMUNITIES, ENRICHMENT, MARSH, PHOTOSYNTHESIS, PLANT GROWTH, RESPONSES, YIELD

2115
Samarakoon, A.B., and R.M. Gifford. 1996. Water use and growth of cotton in response to elevated CO2 in wet and drying soil (vol 23, pg 63, 1996). *Australian Journal of Plant Physiology 23(3):401.*

2116
Samarakoon, A.B., and R.M. Gifford. 1996. Water use and growth of

cotton in response to elevated CO2 in wet and drying soil. *Australian Journal of Plant Physiology 23(1):63-74.*

Cotton (Gossypium hirsutum cv. Sicala 34) was grown at 352 ('low CO2') or 710 ('high CO2') mu L L(-1) atmospheric CO2 in continuously wet soil, or in drying soil, or in drying soil re- wetted after plant wilting. In wet soil, the approximately 15% reduction in transpiration per unit leaf area owing to high CO2 was only half that for other species, whereas effects on growth and leaf area were relatively larger. Consequently, water use per plant was 45-50% higher for high CO2 plants in contrast to other species for which the rate of water use is either the same or lower in high CO2. Greater plant water use early in a drying cycle caused the soil to dry faster under high CO2 than under low CO2. The addition of the consequential greater water stress at high CO2 in drying soil to the direct CO2 effect on stomata caused the transpiration rate of high CO2 plants to fall by up to 60% as the soil dried relative to plants drying at low CO2. After re-wetting the dry soil, the reduction in transpiration rate at high CO2 returned within hours to the value of 15% seen in wet soil. The results were inconsistent with the idea that water deficits increase the sensitivity of stomatal aperture to CO2. Other consequences of drier soil under high CO2 compared with low CO2 were: (a) unlike in many other species, in cotton, the relative growth enhancement by high CO2 is not higher under drying soil compared with wet soil owing to the opposite effect on soil water content; and (b) the increased water-use efficiency in drying soil relative to wet soil was greater in high CO2 plants than in low CO2. The confounding of indirect effects of soil water with the direct CO2 effects may explain the wide variability of literature reports about CO2 effects on stomatal conductance and water use.

KEYWORDS: ABSCISIC- ACID, ATMOSPHERIC CO2, CARBON DIOXIDE, FIELD, LEAF, PHOTOSYNTHETIC RATE, PLANT GROWTH, STOMATAL CONDUCTANCE, TRANSPIRATION, YIELD

2117

Samarakoon, A.B., W.J. Muller, and R.M. Gifford. 1995. Transpiration and leaf-area under elevated co2 - effects of soil-water status and genotype in wheat. *Australian Journal of Plant Physiology 22(1):33-44.*

Transpiration rate, leaf area expansion, water use and water- use efficiency (WUE) of spaced plants of wheat (cvv. Matong and Quarrion), were examined at ambient and twice ambient CO2 concentrations in wet and drying soil regimes. A hypothesis tested was that both stomatal conductance (g(s)) and leaf area development are so regulated by the plant in relation to soil water status that the reduction of approximately 40% in g(s) in high CO2 has no permanent impact on whole-plant water use. Whereas, during a soil drying cycle, leaf area increase under elevated CO2 counterbalanced closely for reduced g(s) in terms of soil water depletion as reported elsewhere, this counterbalance was neither exact at all times, nor did it apply when the soil was continuously wet. In wet soil, leaf area was not enhanced much by elevated CO2, probably because, under the high radiation and nutritional conditions used, the tillering rate was almost maximal anyway. Quarrion, having a 40% lower g(s) than Matong genetically, did not counterbalance a reduced transpiration rate with a larger leaf area under either drying or wet soil conditions. These results support rejection, for wheat, of the hypothesis posed; elevated CO2 increased leaf area mainly by virtue of the direct photosynthetic increase rather than changed soil water status. In wet soil, low g(s) Quarrion had a higher CO2 effect on WUE (+ 73 to 82%) than did Matong (+ 54 to 65%). In drying soil, both cultivars had a similar increase in WUE at high CO2 (+ 60 to 68%).

KEYWORDS: AMBIENT, CARBON-DIOXIDE CONCENTRATION, ENRICHMENT, PLANT GROWTH, RESPONSES, RICE, ROOT RESTRICTION, STRESS, TERM, YIELD

2118

Sampson, D.A., E.J. Cooter, P.M. Dougherty, and H.L. Allen. 1996. Comparison of the UKMO and GFDL GCM climate projections in NPP simulations for southern loblolly pine stands. *Climate Research 7(1):55-69.*

We used the process model BIOMASS version 13.0 to simulate contemporary net primary production (NPP) and NPP response to climate projections for a doubling of atmospheric CO2 concentration from 2 general circulation models (GCMs) that vary in their CO2 sensitivity: the less sensitive GFDL and the more sensitive UKMO. Increased GCM sensitivity to CO2 is reflected in increased predictions in the magnitude, variation, and range of the climate variables. Simulations used a 40 yr historical climate record, and 2 stand and site conditions to standardize the total NPP response estimates for eighteen 1x1 degrees grid cells across the southern United States, Contemporary NPP and NPP response estimates from the 18 cells were smoothed using a cell search algorithm to obtain an NPP response index matrix for the entire loblolly pine (Pinus taeda) forest-type. We conducted a sensitivity analysis of the environmental variables projected to change in a 2xCO(2) environment to help interpret simulation output. Contemporary NPP varied from 2.5 to 8.5 Mg C ha(-1) yr(-1) over the range of loblolly pine, High leaf area index (LAI) simulations had 1.5 to 2 times the productivity of low LAI simulations, but the regional patterns were similar; NPP was correlated with regional differences in precipitation and temperature. The NPP response to future climate and atmospheric changes depended on the GCM used, and on the stand and site condition assumed. Inter-annual estimates for the 18 cell simulations resulted in a +22 to +84% NPP response for the GFDL climate projections and a -30 to +94% NPP response for the UKMO climate projections. The 40-year average NPP response for the smoothed data ranged from +43 to +65% and -1 to +94% for the GFDL and the UKMO climate projections, respectively. Consequently, the magnitude and range of the 40-year average NPP response to the climate projections was directly correlated with the GCM CO2 sensitivity. Although increased CO2 sensitivity resulted in broader extremes in the predicted temperature response, precipitation response for the 2 models was similar. The NPP response was also correlated with the patterns in predicted climate change, with regional differences coupled to local climatic conditions. Climate projections from both models produced similar NPP responses when predicted temperatures and precipitation regimes were similar. Elevated ambient CO2 had a greater effect on NPP response than temperature or precipitation in the sensitivity comparisons. Simulations indicate that a CO2 fertilizer effect, assuming no CO2 acclimation, more than compensates for declines in productivity over most of the loblolly pine forest-type associated with projected decreased precipitation and/or projected low to moderate increases in temperature and, therefore, increased maintenance respiration costs.

KEYWORDS: CO2 CONCENTRATIONS, ELEVATED CARBON-DIOXIDE, FORESTS, GROWTH, LEAF-AREA, MODEL, RADIATA, RESPONSES, SLASH PINE, WATER

2119

Sampson, R.N., M. Apps, S. Brown, C.V. Cole, J. Downing, L.S. Heath, D.S. Ojima, T.M. Smith, A.M. Solomon, and J. Wisniewski. 1993. Workshop summary statement - terrestrial biospheric carbon fluxes - quantification of sinks and sources of co2. *Water, Air, and Soil Pollution 70(1-4):3-15.*

Understanding the role of terrestrial ecosystems in the global carbon (C) cycle has become increasingly important as policymakers consider options to address the issues associated with global change, particularly climate change. Sound scientific theories are critical in predicting how these systems may respond in the future, both to climate change and human actions. In March 1993, 60 scientists from 13 nations gathered

in Bad Harzburg, Germany, to develop a state-of-the- science assessment of the present and likely future C fluxes associated with the major components of the earth's terrestrial biosphere. In the process, particular emphasis was placed on the potential for improving C sinks and managing long-term C sequestration. The majority of the week's work was conducted in eight working groups which independently considered a particular biome or subject area. The working groups considered: the Global Carbon Cycle; Boreal Forests and Tundra; Temperate Forests; Tropical Forests; Grasslands, Savannas and Deserts; Land and Water Interface Zones; Agroecosystems; and Biomass Management. This paper presents a brief overview of their major conclusions and findings. In addition, Table 1 brings together the best estimates from each group as to the current magnitude and estimated future direction of changes in the terrestrial C fluxes.

2120

Samuelson, L.J., and J.R. Seiler. 1992. Fraser fir seedling gas-exchange and growth in response to elevated co2. *Environmental and Experimental Botany 32(4):351-356.*

Growth and gas exchange characteristics were examined in Fraser fir (Abies fraseri (Pursh.) Poir.) seedlings grown from seed in elevated (713 ppm) or ambient (374 ppm) CO2 for 1 year (two artificial growing seasons) to determine the potential influence of a twice-ambient CO, concentration on this species. A subset of seedlings was transplanted from 172 cm3 pots into 1000 cm3 pots at 7 months to determine if CO2 effects were dependent on rooting volume. At 5 and 12 months, net photosynthesis (P(net)) and leaf conductance (g1) were lower in elevated CO2-grown seedlings grown in 172 cm3 pots than in ambient CO2-grown seedlings when measured at either 346 or 796 ppm CO2. For 12-month-old seedlings grown in 1000 cm3 pots, P(net) was reduced by an elevated CO2 growth environment only when measured at 346 ppm CO2, although g1 was lower in these seedlings when measured at either CO2 measurement level. Seedlings grown in both pot sizes and in elevated CO2 for 1 year had greater height, diameter, and leaf, stem, root and total dry weights than seedlings grown in ambient CO2. Specific leaf weight (SLW) was greater in elevated than in ambient CO2- grown needles only in the large pot size treatment. These results suggest that Fraser fir seedling growth will increase in a future elevated CO2 environment despite changes in gas exchange characteristics.

KEYWORDS: ATMOSPHERIC CO2, INCREASE

2121

Samuelson, L.J., and J.R. Seiler. 1993. Interactive role of elevated co2, nutrient limitations, and water-stress in the growth-responses of red spruce seedlings. *Forest Science 39(2):348-358.*

Red spruce (Picea rubens Sarg.) seedlings were grown from seed for 5 mo in ambient (362 ppm) or elevated (711 ppm) CO2 to determine the potential effect of an increase in global CO2 concentration on seedling growth and establishment. CO2 exposure treatments were crossed with two levels of soil fertility and water stress treatments to determine if seedling dry weight, size, and fixed growth responses to elevated CO2 depended on nutrient and water supply. Seedling dry weight and size responses to elevated CO2 at 5 mo did not depend on nutrient and water supply. Seedlings grown in both soil fertility treatments and water stress treatments responded similarly to CO2 treatment. Water stress and CO2 treatments did have an interactive influence on the fixed growth potential of the terminal leader. Leaf weight, leaf area, and height of the terminal leader of water-stressed seedlings were greater in seedlings exposed to elevated CO2 during budset than seedlings exposed to ambient CO2. Total new fixed growth (lateral plus terminal) and total terminal fixed growth (leaf plus stem) were greater in seedlings that formed shoot primordia in elevated CO2 than in ambient CO2. Red spruce seedlings grown in elevated CO2 for 5 mo had greater stem diameter, height, branching density, leaf weight, root weight, stem weight, total weight, and mean relative growth rate (RGR) from 3 to 5 mo than seedlings grown in ambient CO2. Red spruce seedling responses to elevated CO2 suggest that seedling establishment in natural environments may be enhanced when ambient CO2 concentrations rise even if water and nutrient availabilities are limited.

KEYWORDS: CARBON DIOXIDE, ENRICHMENT, NUTRITION, PATTERNS, PINE, STANDS

2122

Samuelson, L.J., and J.R. Seiler. 1994. Red spruce seedling gas-exchange in response to elevated co2, water-stress, and soil fertility treatments. *Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 24(5):954-959.*

The interactive influences of ambient (374 muL.L-1) or elevated (713 muL.L-1) CO2, low or high soil fertility, well-watered or water-stressed treatment, and rooting volume on gas exchange and growth were examined in red spruce (Picea rubens Sarg.) grown from seed through two growing seasons. Leaf gas exchange throughout two growing seasons and growth after two growing seasons in response to elevated CO2 were independent of soil fertility and water-stress treatments, and rooting volume. During the first growing season, no reduction in leaf photosynthesis of seedlings grown in elevated CO2 compared with seedlings grown in ambient CO2 was observed when measured at the same CO2 concentration. During the second growing season, net photosynthesis was up to 21% lower for elevated CO2-grown seedlings than for ambient CO2-grown seedlings when measured at 358 muL.L-1. Thus, photosynthetic acclimation to growth in elevated CO2 occurred gradually and was not a function of root- sink strength or soil-fertility treatment. However, net photosynthesis of seedlings grown and measured at an elevated CO2 concentration was still over 2 times greater than the photosynthesis of seedlings grown and measured at an ambient CO2 concentration. Growth enhancement by CO2 was maintained, since seedlings grown in elevated CO2 were 40% larger in both size and weight after two growing seasons.

KEYWORDS: CARBON DIOXIDE, ENRICHMENT, GROWTH-RESPONSES, NUTRIENT-UPTAKE, PHOTOSYNTHESIS, PHYSIOLOGY, RISING CO2, STANDS, TREES

2123

Sanders, I.R., R. Streitwolf-Engel, M.G.A. van der Heijden, T. Boller, and A. Wiemken. 1998. Increased allocation to external hyphae of arbuscular mycorrhizal fungi under CO2 enrichment. *Oecologia 117(4):496-503.*

Prunella vulgaris is was inoculated with different arbuscular mycorrhizal fungi (AMF) and grown at two concentrations of CO2 (ambient, 350 mu l l(-1), and elevated, 600 mu l l(-1)) to test whether a plants response to elevated CO2 is dependent on the species of AMF colonizing the roots. Using compartments accessible only to AMF hyphae but not to roots, we also tested whether elevated CO2 affects the growth of external AMF hyphae. Plant biomass was significantly greater at elevated than at ambient CO2; the biomass of the root system, for example, increased by a factor of 2. The colonization of AMF inside the root remained constant, indicating that the total AMF inside the root system also increased by a factor of 2. The length of external AMF hyphae at elevated CO2 was up to 5 times that at ambient CO2, indicating that elevated CO2 promoted allocation of AMF biomass to the external hyphae. The concentration and content of phosphorus in the stolons differed significantly between ambient and elevated CO2 but this resulted in either an increase or a decrease, according to which AMF isolate occupied the roots. We hypothesized that an increase in external

hyphal growth at elevated CO2 would result in increased P acquistion by the plant. To test this we supplied phosphorus, in a compartment only accessible to AMF hyphae. Plants did not acquire more phosphorus at elevated CO2 when phosphorus was added to this compartment. Large increases in AMF hyphal growth could, however? play a significant role in the movement of fixed carbon to the soil and increase soil aggregation.

KEYWORDS: CARBON DIOXIDE, COLONIZATION, ELEVATED CO2, GROWTH, ROOTS

2124

Santrucek, J., and R.F. Sage. 1996. Acclimation of stomatal conductance to a CO2-enriched atmosphere and elevated temperature in Chenopodium album. *Australian Journal of Plant Physiology 23(4):467-478.*

Acclimation of stomatal conductance to different CO2 and temperature regimes was determined in Chenopodium album L. plants grown at one of three treatment conditions: 23 degrees C and 350 mu mol CO2 mol(-1) air; 34 degrees C and 350 mu mol mol(-1); and 34 degrees C and 750 mu mol mol(-1). Stomatal conductance (g(s)) as a function of intercellular CO2 (C-i) was determined for each treatment at 25 and 35 degrees C, and these data were used to estimate gains of the feedback loops linking changes in intercellular CO2 with stomatal conductance and net CO2 assimilation. Growth temperature affected the sensitivity of stomata to measurement temperature in a pattern that was influenced by intercellular CO2. Stomatal conductance more than doubled at intercellular CO2 varying between 200 and 600 mu mol mol(-1) as leaf temperature increased from 25 to 35 degrees C for plants grown at 23 degrees C. In contrast, stomatal conductance was almost unaffected by measurement temperature in plants grown at 34 degrees C. Elevated growth CO2 attenuated the response of stomatal conductance to CO2, but growth temperature did not. Stomatal sensitivity to C-i was extended to higher C-i in plants grown in elevated CO2. As a result, plants grown at 750 mu mol mol(-1) CO2 had higher C-i/C-a at ambient CO2 values between 300 and 1200 mu mol mol(-1) than plants grown at 350 mu mol mol(-1) CO2. The gain of the stomatal loop was reduced in plants grown at elevated CO2 or at lower temperature when compared to plants grown at 350 mu mol mol(-1) and 34 degrees C. Both photosynthetic and stomatal loop gains acclimated to elevated CO2 in proportion so that their ratio, integrated over the range of C-i in which the plant operates, remained constant. Water use efficiency (WUE) more than doubled after a short-term doubling of ambient CO2. However, the WUE of plant grown and measured at elevated CO2 was only about 1.5 times that of plant transiently exposed to elevated CO2, due to stomatal acclimation. An optimal strategy of water use was maintained for all growth treatments.

KEYWORDS: C-3 PLANTS, CARBON DIOXIDE, CO2 ASSIMILATION, GAIN, HUMIDITY, LEAF CONDUCTANCE, LIGHT, PHOTOSYNTHESIS, RESPONSES, WATER-USE EFFICIENCY

2125

Santrucek, J., H. Santruckova, J. Kveton, M. Simkova, and K. Rohacek. 1994. The effect of elevated co2 concentration on photosynthetic co2 fixation, respiration and carbon economy of wheat plants. *Rostlinna Vyroba 40(8):689-696.*

Winter wheat plants were grown under controlled atmospheric and light conditions for 25 days to assess the response of photosynthesis, respiration and carbon allocation to elevated ambient CO2 concentration. Daily balance of carbon fixation and loss was measured separately for shoots and roots including root exudation. Doubled CO2 (700 mumol CO2 mol-1) stimulated photosynthetic CO2 uptake and dark respiration rate when calculated on the leaf area basis. However, total daily carbon gain per plant and total dry matter of shoot was lower for high-CO2-grown plants due to reduced leaf area. After 23 days of exposition to high CO2, photosynthesis was depressed probably due to limiting regeneration of ribulose bisphosphate. Both stomatal resistance and water use efficiency were markedly higher in high-CO2-grown plants. Higher evaporative demand in low-CO2-grown plants promoted root elongation. Total root length was 160% of that in high-CO2-grown plants. Root exudation of high-CO2-grown plants was higher in the first days of plant development, but the inhibition of net photosynthesis was followed by a decrease in exudation.

2126

Santruckova, H., J. Santrucek, J. Kveton, M. Simkova, D. Elhottova, and K. Rohacek. 1999. Carbon balance of a winter wheat-root microbiota system under elevated CO2. *Photosynthetica 36(3):341-354.*

We examined the carbon budget of young winter wheat plants and their associated microorganisms as affected by a doubling of the atmospheric CO2 concentration (700 mu mol mol(-1)). Plants were grown hydroponically in pre-sterilised sand at a controlled irradiance and temperature regime. Net photosynthesis (P-N) and respiration (R-D) rates of roots and shoots were measured continuously, plant growth and carbon distribution in the plant-root medium-associated microorganism system were determined destructively in interval-based analyses. P-N in elevated CO2 grown plants (EC) was 123 % of that in the control (AC) plants when averaged over the whole life span (39-d-old plants, 34 d in EC), but the percentage varied with the developmental stage being 115, 88, and 167 % in the pretillering, tillering, and posttillering phase, respectively. There was a transient depression of P-N, higher amplitude of day/night fluctuations of the chloroplast starch content, and depression of carbon content in rhizosphere of EC plants during the period of tillering. After 34 d in EC, carbon content in shoots,'roots, and in rhizodepositions was enhanced by the factors 1.05, 1.28, and 1.96, respectively. Carbon partitioning between above and belowground biomass was not affected by EC, however, proportionally more C in the belowground partitioning was allocated into the root biomass, Carbon flow from roots to rhizodepositions and rhizosphere microflora was proportional to P-N; its fraction in daily assimilated carbon decreased from young (17 %) to older (3-4 %) plants.

KEYWORDS: ATMOSPHERIC CO2, ENRICHMENT, GAS-EXCHANGE, GROWTH, NITROGEN, PHOTOSYNTHESIS, RESPONSES, RHIZOSPHERE, SOIL, TRITICUM-AESTIVUM L

2127

Santruckova, H., and M. Simek. 1997. Effect of soil CO2 concentration on microbial biomass. *Biology and Fertility of Soils 25(3):269-273.*

The effect of increasing soil CO2 concentration was studied in six different soils. The soils were incubated in ambient air (0.05 vol.% CO2) or in air enriched with CO2 (up to 5.0 vol.% CO2). Carbon dioxide evolution, microbial biomass, growth or death rate quotients and glucose decay rate were measured at 6, 12 and 24 h of CO2 exposure. The decrease in soil respiration ranged from 7% to 78% and was followed by a decrease in microbial biomass by 10-60% in most cases. High CO2 treatments did not affect glucose decay rate but the portion of C-gluc mineralized to CO2 was lowered and a larger portion of C-gluc remained in soils. This carbon was not utilized by soil microorganisms.

KEYWORDS: CARBON DIOXIDE, LAND, MICROORGANISMS, RESPIRATION

2128

Saralabai, V.C., M. Vivekanandan, and R.S. Babu. 1997. Plant responses to high CO2 concentration in the atmosphere. *Photosynthetica 33(1):7-37.*

The impact of continuous rise in ambient CO2 concentration (AC) in the atmosphere on different facets of growth of crop plants is assessed. The effects of CO2 enrichment (EC) on plant growth, C-3 and C-4 photosynthesis, source-sink ratio, partitioning and translocation of metabolites, photosynthetic enzymes, respiratory rate, leaf area index, stomatal conductance (g(s)), transpiration rate, biomass production and water use efficiency are reviewed. The CO2 fertilization effects are studied in both short-term (open top chambers) and long-term experiments. Long-term experiments suggest that ribulose-1,5-bisphosphate carboxylase is inactivated at high CO2 concentrations. Also g(s) is lowered. One of the conspicuous effects of EC is the closure of stomata in C-3 plants. Photosystem (PS) 2 electron transport is more affected than PS1. Starch is the immediate product accumulated in the leaf of C-3 plants. The "CO2 fertilization effect" does not confer any great advantage even in C-3 plants.

KEYWORDS: DARK RESPIRATION, DRY-MATTER PRODUCTION, ELEVATED CARBON-DIOXIDE, LOLIUM-PERENNE, LONG-TERM EXPOSURE, PHASEOLUS-VULGARIS, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, SOYBEAN CANOPY PHOTOSYNTHESIS, SWEET-POTATO, WATER-USE EFFICIENCY

2129
Sasek, T.W., and B.R. Strain. 1990. Implications of atmospheric CO2 enrichment and climatic-change for the geographical-distribution of 2 introduced vines in the USA. *Climatic Change 16(1):31-51.*

2130
Sasek, T.W., and B.R. Strain. 1991. Effects of CO2 enrichment on the growth and morphology of a native and an introduced honeysuckle vine. *American Journal of Botany 78(1):69-75.*

Japanese honeysuckle (Lonicera japonica Thunb.), introduced to the United States, and the native coral honeysuckle (Lonicera sempervirens L.) were compared to determine how intrinsic differences in their growth characteristics would affect their response to atmospheric carbon dioxide enrichment. Plants of both species grown from cuttings were harvested after 54 days of growth in controlled environment growth chambers at 350, 675, or 1,000-mu-l/liter CO2. The biomass of Japanese honeysuckle was increased 135% at 675-mu-l/liter CO2 and 76% at 1,000-mu-l/liter CO2 after 54 days. Morphologically, the main effect of CO2 enrichment was to triple the number of branches and to increase total branch length six times. Enhanced and accelerated branching also increased total leaf area 50% at elevated CO2 concentrations. In coral honeysuckle, total biomass was only 40% greater in the elevated CO2 treatments. Branching was quadrupled but had not proceeded long enough to affect total leaf area. Main stem height was increased 36% at 1,000-mu-l/liter CO2. The much less significant height response of other woody erect growth forms suggests that vines may increase in importance during competition if atmospheric CO2 concentrations increase as predicted. The impact of Japanese honeysuckle in the United States may become more serious.

KEYWORDS: ATMOSPHERIC CO2, CARBON-DIOXIDE ENRICHMENT, CLIMATE, KUDZU PUERARIA-LOBATA, LIQUIDAMBAR- STYRACIFLUA

2131
Sato, H., N. Sakurai, S. Sendo, H. Saneoka, H. Nobuyasu, and K. Fujita. 1997. Factors affecting leaf area development in husk leaf of flint corn. *Crop Science 37(6):1826-1831.*

Some corn (Zea mays L.) genotypes produce husk leaves (laminae extending from the husk) that on a per unit area basis, contribute more photosynthate to grain production than culm leaves. Furthermore, a high correlation between husk leaf area and dry weight has been observed, but little is known about the changes in cell components during development of husk leaves. A field experiment was conducted to quantify methanol (MeOH)- soluble fraction (cytosol) and incorporation of C-13-labeled photosynthate in cell walls from 9 d before silking (DBS) to silking. The ear leaf of flint corn (F-1 of N-19 by X-15) was subjected to (CO2)-C-13, eight DBS. Leaf area, dry weight, and photosynthetic activity of the husk leaves, and sugar content of various cell components were measured continuously during the 9-d period. The husk leaf attained one-half of its maximum apparent photosynthetic rate (P-0,) when it had 8% of its maximum leaf area at 4 DES. At 9 DBS, neutral sugars in the MeOH-soluble fraction accounted for most of nonstarch carbohydrates within the husk leaf (68%), while hemicellulose and cellulose fractions accounted for <10%. At silking, however, sugars in the hemicellulose and cellulose fractions increased by 23 and 56%, respectively. Results of (CO2)-C-13 labeling suggest that during rapid husk leaf development, MeOH- soluble fraction decreases, while the hemicellulose fraction fluctuates, and cellulose fraction increases.

KEYWORDS: DRY-MATTER, ELEVATED CO2, EXTENSION, GROWTH, HYPOCOTYLS, LEAVES, SWEET CORN, WALLS

2132
Saurer, M., S. Maurer, R. Matyssek, W. Landolt, M.S. Gunthardtgoerg, and U. Siegenthaler. 1995. The influence of ozone and nutrition on delta-C-13 in betula- pendula. *Oecologia 103(4):397-406.*

In the cellulose of stems and leaves, delta(13)C was investigated in a birch clone (Betula pendula), which was exposed throughout the growing season to either <3 (control) or 90/40 nl O-3 1(-1) (day/night). Each regime was split into plants under high or low nutrient supply. delta(13)C was increased (becoming less negative), in stems rather than leaves, by both high nutrition (+2 parts per thousand) and O-3 stress (+1 parts per thousand). Whereas high nutrition raised the water-use efficiency (WUE) while lowering the CO2 concentration in the inner leaf air space (c(i)), WUE decreased and c(i) increased under O-3 stress. Therefore, only the nutritional effect on the carbon isotope fractionation was reproduced by the model of Farquhar et al. (1982) which estimates WUE by means of delta(13)C based on C-i, C-i was not biased by 'patchiness' in respect to stomatal opening. The latter was verified by microscopical analysis and the complete water infiltration of the birch leaves through the stomata, independent of the diurnal course of the leaf conductance for water vapour. Under low nutrient supply, the activity of phosphoenol pyruvate carboxylase (PEPC) was roughly doubled by ozone to about 1.3% of the total carboxylation capacity (by PEPC + rubisco), and was increased to 1.7% under high nutrition. The fractionation model, extended to account for varying activities of the carboxylating enzymes, indicated that stimulated PEPC was the cause of elevated delta(13)C, although c(i) was increased under O-3 stress. The stimulation of PEPC and, as a consequence, elevated delta(13)C are discussed as part of a whole-plant acclimation to O-3 stress.

KEYWORDS: ABSCISIC-ACID, BIRCH LEAVES, CARBON ISOTOPE DISCRIMINATION, CO2, DECLINE, GAS-EXCHANGE, GROWTH, NET PHOTOSYNTHESIS, PLANTS, WATER-VAPOR EXCHANGE

2133
Saxe, H. 1994. Relative sensitivity of greenhouse pot plants to long-term exposures of no-containing and no2-containing air. *Environmental Pollution 85(3):283-290.*

Thirty-five cultivars of pot plants of 20 families were exposed for 50-64 days in a greenhouse facility to either 1 mul litre-1 NO with 0.5 mul litre-1 NO2, or 1 mul litre-1 NO2 with 0.1 mul litre-1 NO for 15 h each day, with air which was free from these gases as the reference. A sensitivity ranking of the pot plants was compiled, with the highest priority on visible injuries, followed by growth reductions, primarily as a response to the NO-dominated exposures, simulating the NO(x)-polluted environment in direct-fired, CO2-enriched greenhouses. This treatment reduced the leaf dry weight more than the number and area of the leaves. Twenty-two cultivars were significantly injured, while two (Hibiscus sp., Epipremnum pinnatum, green) were significantly improved. The NO(x)-sensitivity of pot plants was highest in cultivars with variegated, small or narrow leaves, and in the Moraceae family. Nine cultivars (Ficus elastica 'Robusta, F. benjamina, F. pumila 'Sonny, Dieffenbachia maculata 'Camilla', F. elastica 'Tineke, Epipremnum pinnatum 'Marble Queen', Begonia elatior 'Nelson, Cyclamen persica, Poinsettia 'Mini) were specifically sensitive to the NO-containing exposure; six were specifically sensitive to the NO2-containing exposure (F. elastica 'Robusta', Asparagus den. 'Sprengeri, Hedera helix 'Shamrock, Aspledium nidus, Aster novo-belgii, Hypoestes phyl. 'Betina); and 12 (Soleirolia soleirolii, Asparagus den. 'Sprengeri, H. helix 'Ester, Codiaeum 'Pictum, Rosa 'Minimo Red, F. benjamina 'Starlight, Saintpaulia ionantha 'light blue', F. pumila, Rhododendron simsii, H. helix 'Shamrock', Hibiscus sp., E. pinnatum) were equally sensitive to mixtures dominated by either gas, as measured by at least one response parameter.

KEYWORDS: CARBON DIOXIDE, CO2, NET PHOTOSYNTHESIS, NITROGEN-DIOXIDE, OXIDES, POLLUTION

2134

Saxe, H., D.S. Ellsworth, and J. Heath. 1998. Tree and forest functioning in an enriched CO2 atmosphere. *New Phytologist 139(3):395-436.*

Forests exchange large amounts of CO2 with the atmosphere and can influence and be influenced by atmospheric CO2. There has been a recent proliferation of literature on the effects of atmospheric CO2 on forest trees. More than 300 studies of trees on five different continents have been published in the last five years. These include an increasing number of field studies with a long-term focus and involving CO2 x stress or environment interactions. The recent data on long-term effects of elevated atmospheric CO2 on trees indicate a potential for a persistent enhancement of tree growth for several years, although the only relevant long-term datasets currently available are for juvenile trees. The current literature indicates a significantly larger average long-term biomass increment under elevated CO2 for conifers (130%) than for deciduous trees (49%) in studies not involving stress components. However, stimulation of photosynthesis by elevated CO2 in long-term studies was similar for conifers (62 %) and deciduous trees (53 %). Recent studies indicate that elevated CO2 causes a more persistent stimulation of biomass increment and photosynthesis than previously expected. Results of seedling studies, however, might not be applicable to other stages of tree development because of complications of age- dependent and size-dependent shifts in physiology and carbon allocation, which are accelerated by elevated CO2. In addition, there are many possible avenues to down-regulation, making the predicted canopy CO2 exchange and growth of mature trees and forests in a CO2-rich atmosphere uncertain. Although, physiological down-regulation of photosynthetic rates has been documented in field situations, it is rarely large enough to offset entirely photosynthetic gains in elevated CO2. A persistent growth stimulation of individual mature trees has been demonstrated although this effect is more uncertain in trees in natural stands. Resource interactions can both constrain tree responses to elevated CO2 and be altered by them. Although drought can reduce gas-exchange rates and offset the benefits of elevated CO2, even in well watered trees, stomatal conductance is remarkably less responsive to elevated CO2 than in herbaceous species. Stomata of a number of tree species have been demonstrated to be unresponsive to elevated CO2. We conclude that positive effects of CO2 on leaf area can be at least as important in determining canopy transpiration as negative, direct effects of CO2 on stomatal aperture. With respect to nutrition, elevated CO2 has the potential to alter tree-soil interactions that might influence future changes in ecosystem productivity. There is continued evidence that in most cases nutrient limitations diminish growth and photosynthetic responses to elevated CO2 at least to some degree, and that elevated CO2 can accelerate the appearance of nutrient limitations with increasing time of treatment. In many studies, tree biomass responses to CO2 are artefacts in the sense that they are merely responses to CO2-induced changes in internal nutritional status of the tree. There are numerous interactions between CO2 and factors of the biotic and abiotic environment. The importance of increasing atmospheric CO2 concentrations for productivity is likely to be overestimated if these are not taken into account. Many interactions, however, are simply additive rather than synergistic or antagonistic. This appears to hold true for many parameters under elevated CO2 in combination with temperature, elevated O- 3, and other atmospheric pollutants. However, there is currently little evidence that elevated CO2 will counteract O-3 damage. When the foliage content of C, mineral nutrients and secondary metabolites is altered by elevated CO2, tree x insect interactions are modified. In most trees, mycorrhizal interactions might be less important for direct effects of CO2 than for alleviating general nutrient deficiencies. Since many responses to elevated CO2 and their interactions with stress show considerable variability among species/genotypes, one principal research need is for comparative studies of a large variety of woody species and ecosystems under realistic conditions. We still need more long-term experiments on mature trees and stands to address critical scaling issues likely to advance our understanding of responses to elevated CO2 at different stages of forest development and their interactions with climate and environment. The only tools available at present for coping with the consequences of rising CO2 are management of resources and selection of genotypes suitable for the future climate and environment.

KEYWORDS: BEECH FAGUS- SYLVATICA, BETULA-PENDULA ROTH, CO2-INDUCED GROWTH ENHANCEMENTS, ELEVATED CARBON-DIOXIDE, GAS-EXCHANGE RESPONSES, LONG-TERM EXPOSURE, PICEA-ABIES L, PONDEROSA PINE- SEEDLINGS, SITCHENSIS BONG CARR, WATER-LOSS REGULATION

2135

ScarasciaMugnozza, G., P. DeAngelis, G. Matteucci, and R. Valentini. 1996. Long-term exposure to elevated [CO2] in a natural Quercus ilex L community: Net photosynthesis and photochemical efficiency of PSII at different levels of water stress. *Plant, Cell and Environment 19(6):643-654.*

Naturally grown trees of Mediterranean evergreen oak (Quercus ilex L.), representing the climax species of the region, were enclosed in six large open-top chambers and exposed to ambient and elevated CO2 concentrations during a 3 year period, Maximum daily net photosynthetic rates measured at the two different CO2 concentrations were from 30 to 100% higher in elevated than in ambient [CO2] throughout the experimental period, The increase in maximum daily photosynthesis was also accompanied by a 93% rise in the apparent quantum yield of CO2 assimilation, measured during periods of optimum soil moisture conditions, Hence, no clear evidence of downregulation of net photosynthetic activity was found, Interactions between atmospheric CO2 concentration and plant water stress were studied by following the natural evolution of drought in different seasons and years, At each level of water stress, the maximum rate of carbon assimilation was higher in elevated than in ambient [CO2] by up to 100%. Analysis of in vivo chlorophyll fluorescence parameters in normal (21%) and low (2%) oxygen concentrations provided useful insights into

the functioning and stability of the photosynthetic processes, The photochemical efficiency of PSII (F-v/F-m) progressively decreased as drought conditions became more evident; this trend was accentuated under elevated [CO2]. Thermal de-excitation processes were possibly more significant under elevated than under ambient [CO2], in a combination of environmental stresses. This research suggests two possible conclusions: (i) a 'positive' interaction between elevated [CO2] and carbon metabolism can be obtained through relief of water stress limitation in the summer months, and (ii) elevated [CO2], under drought conditions, may also enhance the significance of slow- relaxing quenching.

KEYWORDS: CARBON DIOXIDE, CHLOROPHYLL FLUORESCENCE, ELECTRON-TRANSPORT, GAS-EXCHANGE, LEAVES, O-2 EVOLUTION, PHOTON YIELD, PHOTOSYSTEM, QUANTUM YIELDS, VASCULAR PLANTS

2136

Schaffer, B., C. Searle, A.W. Whiley, and R.J. Nissen. 1996. Effects of atmospheric CO2 enrichment and root restriction on leaf gas exchange and growth of banana (Musa). *Physiologia Plantarum 97(4):685-693.*

The effects of atmospheric CO2 enrichment and root restriction on photosynthetic characteristics and growth of banana (Musa sp, AAA cv. Gros Michel) plants were investigated. Plants were grown aeroponically in root chambers in controlled environment glasshouse rooms at CO2 concentrations of 350 or 1000 mu mol CO2 mol(-1). At each CO2 concentration, plants were grown in large (200 l) root chambers that did not restrict root growth or in small (20 l) root chambers that restricted root growth. Plants grown at 350 pmol CO2 mol(-1) generally had a higher carboxylation efficiency than plants grown at 1 000 mu mol CO2 mol(-1), although actual net CO2 assimilation (A) was higher at the higher ambient CO2 concentration due to increased intercellular CO2 concentrations (Ci) resulting from CO2 enrichment. Thus, plants grown at 1 000 mu mol CO2 mol(-1) accumulated more leaf area and dry weight than plants grown at 350 mu mol CO2 mol(-1). Plants grown in the large root chambers were more photosynthetically efficient than plants grown in the small root chambers. At 350 mu mol CO2 mol(-1), leaf area and dry weights of plant organs were generally greater for plants in the large root chambers compared to those in the small root chambers. Atmospheric CO2 enrichment may have compensated for the effects of root restriction on plant growth since at 1 000 mu mol CO2 mol(-1) there was generally no effect of root chamber size on plant dry weight.

KEYWORDS: AAA, CAVENDISH SUBGROUP, ELEVATED CARBON-DIOXIDE, LEAVES, LIGHT, PHOTOSYNTHETIC ACCLIMATION, PHYSIOLOGICAL-RESPONSES, PLANTS, STRESS, SUBTROPICS

2137

Schaffer, B., A.W. Whiley, and C. Searle. 1999. Atmospheric CO2 enrichment, root restriction, photosynthesis, and dry-matter partitioning in subtropical and tropical fruit crops. *Hortscience 34(6):1033-1037.*

KEYWORDS: CARBON-DIOXIDE ENRICHMENT, ELEVATED CO2, GENE-EXPRESSION, GROWTH, LEAF GAS- EXCHANGE, LEAVES, NET PHOTOSYNTHESIS, NITROGEN, PLANTS, SOUR ORANGE TREES

2138

Schaffer, B., A.W. Whiley, C. Searle, and R.J. Nissen. 1997. Leaf gas exchange, dry matter partitioning, and mineral element concentrations in mango as influenced by elevated atmospheric carbon dioxide and root restriction. *Journal of the American Society for Horticultural Science 122(6):849-855.*

The effects of atmospheric CO2 enrichment and root restriction on net CO2 assimilation (A), dry mass partitioning, and leaf mineral element concentrations in 'Kensington' and 'Tommy Atkins' mango (Mangifera indica L.) were investigated. Trees were grown in controlled-environment glasshouse rooms at ambient CO2 concentrations of 350 or 700 mu mol.mol(-1). At each CO2 concentration, trees were grown in 8-L containers, which restricted root growth, or grown aeroponically in 200-L root mist chambers, which did not restrict root growth. Trees grown in 350 mu mol.mol(-1) CO2 were more efficient at assimilating CO2 than trees grown in 700 mu mol.mol(-1) CO2. However, total plant and organ dry mass was generally higher for plants grown at 700 mu mol.mol(-1) CO2 due to increased A as a result of a greater internal partial pressure of CO2 (Ci) in leaves of plants in the CO2 enriched environment. Root restriction reduced A resulting in decreased organ and plant dry mass. In root-restricted plants, reduced A and dry matter accumulation offset the increases in these variables resulting from atmospheric CO2 enrichment. Atmospheric CO2 enrichment and root restriction did not affect dry mass partitioning. Leaf mineral element concentrations were generally lower for trees grown at the higher ambient CO2 concentration, presumably due to a dilution effect from an increased growth rate.

KEYWORDS: CO2- ENRICHMENT, GROWTH, NITROGEN, PHOTOSYNTHETIC ACCLIMATION, PLANTS, RESPONSES, WHEAT

2139

Schapendonk, A.H.C.M., P. Dijkstra, J. Groenwold, C.S. Pot, and S.C. vandeGeijn. 1997. Carbon balance and water use efficiency of frequently cut Lolium perenne L swards at elevated carbon dioxide. *Global Change Biology 3(3):207-216.*

The impact of doubled atmospheric [CO2] on the carbon balance of regularly cut Lolium perenne L. swards was studied for two years under semi-field conditions in the Wageningen Rhizolab. CO2 and H2O vapour exchange rates of the swards were measured continuously for two years in transparent enclosures. The light utilization efficiencies of the swards ranged between 1.5 g CO2 MJ(-1) global radiation (high light, ambient [CO2]) and 2.8 g CO2 MJ(-1) (low light, doubled [CO2]). The above-ground net primary productivity (NPP) in the enclosures was greater by 29% in 1994 and 43% in 1995 in the doubled [CO2] treatments, but only 20% and 25% more carbon was recovered in the periodical cuts. Thus, NPP increased significantly more than did the harvested aboveground biomass. The positive [CO2] effect on net carbon assimilation is therefore associated with a preferential allocation of extra carbon to the roots and soil. In addition to higher canopy photosynthesis and leaf elongation rates, a small part of the positive [CO2] effects on NPP could be attributed to a decrease of the specific respiration of the shoots. On a canopy basis however, respiration was equal or slightly higher at doubled [CO2] due to the higher amount of standing biomass. Comparison of NPP and carbon recovered in different harvests showed that allocation to roots and soil was highest in spring, it was low in early summer and increased again in late summer and autumn. The total gross amount of carbon partitioned to the roots and soil during the two year period was 57% more at doubled [CO2]. The total amount of carbon that was sequestered in the soil after subtraction of the respiratory losses was 458 g m(-2) and 779 g m(-2) in the ambient and doubled [CO2] treatments, respectively. The average water use efficiency (WUE) of the swards was increased by a factor 1.5 at doubled [CO2]. Both WUE and its positive interaction with [CO2] varied between years and were positively correlated with global irradiance. At doubled [CO2], the higher WUE was fully compensated for by a higher leaf area index. Therefore, total transpiration on a canopy basis was equal for the ambient and the doubled [CO2] concentrations in both years.

KEYWORDS: ATMOSPHERIC CO2, BIOSPHERE, CONDUCTANCE, CYCLE, GRASSLAND, IMPACT, PHOTOSYNTHESIS, RESPIRATION, RYEGRASS, TEMPERATURE

2140

Schapendonk, A.H.C.M., W. Stol, D.W.G. van Kraalingen, and B.A.M. Bouman. 1998. LINGRA, a sink/source model to simulate grassland productivity in Europe. *European Journal of Agronomy 9(2-3):87-100.*

A simulation model for the prediction of the productivity of Lolium perenne L. grasslands is described and validated. Simulated key processes are light utilization, leaf formation, leaf elongation, tillering, and carbon partitioning (storage, shoot, root). Source- and sink-limited growth are simulated independently. Sink-limited growth is characterized by temperature-dependent leaf expansion and tiller development, whereas source-limited growth is determined by photosynthetic light-use-efficiency of the canopy and the remobilization of stored carbohydrates in the stubble. At each integration step, commonly 1 day, the available amount of carbon from the source is compared with the carbon required by the sink. The actual growth is determined by the minimum value of either the sink or the source. If the source is in excess of the sink, the surplus is allocated to storage carbohydrates in the stubble. This storage carbon is available for remobilization at times that the sink requires more carbohydrates than are available from photosynthesis. In contrast to previous grassland models, LINGRA describes regrowth after defoliation in a mechanistic way, balanced by temperature-driven remobilization of stored carbohydrates. In order to validate LINGRA, an extensive set of experimental data was used, derived from measurements at 35 sites in Europe. The average error between the observed and predicted yields was 14% at the level of irrigated, and 19% at the level of non-irrigated, treatments for the whole of Europe.

KEYWORDS: CARBON BALANCE, CLIMATE, CO2- ENRICHMENT, EFFICIENCY, GROWTH, SENESCENCE, SWARD, TEMPERATURE INCREASE, WATER

2141

Schappi, B. 1996. Growth dynamics and population development in an alpine grassland under elevated CO2. *Oecologia 106(1):93-99.*

Leaf expansion, population dynamics and reproduction under elevated CO2 were studied for two dominant and four subdominant species in a high alpine grassland (2500 above sea level, Swiss Central Alps). Plots of alpine heath were exposed to 335 mu l l(-1) and 680 mu l l(-1) CO2 in open-top chambers over three growing seasons. Treatments also included natural and moderately improved mineral nutrient supply (40 kg N ha(-1) year(-1) in an NPK fertilizer mix). Seasonal dynamics of leaf expansion, which was studied for the dominant graminoid Carer curvula only, were not affected by elevated CO2 during two warm seasons or during a cool season. Improved nutrient supply increased both the expansion rate and the duration of leaf growth but elevated CO2 did not cause any further stimulation. Plant and tiller density (studied in all species) increased under elevated CO2 in the codominant Leontodon helveticus and the subdominant Trifolium alpinum, remained unchanged in two other minor species Poa alpina and Phyteuma globulariifolium, and decreased in Carex curvula. In Potentilla aurea elevated CO2 compensated for a natural decline in shoot number. By year 3 the number of fertile shoots in Leontodon and individual seed weight in Carex were slightly increased under elevated CO2, indicating CO2 effects on sexual reproduction in these two dominant species. The results suggest that the effects of elevated CO2 on the population dynamics of the species studied were not general, but species-specific and rather moderate effects. However, the reduction of tiller density in Carex curvula, in contrast to the increases observed in Leontodon helveticus and Trifolium alpinum, indicates that elevated CO2 may negatively affect the abundance of the species most characteristic of this alpine plant community.

KEYWORDS: ANNUALS, CARBON DIOXIDE, PLANT, REPRODUCTION, TEMPERATURE, TUSSOCK TUNDRA, WHITE CLOVER

2142

Schappi, B., and C. Korner. 1996. Growth responses of an alpine grassland to elevated CO2. *Oecologia 105(1):43-52.*

Alpine plant species have been shown to exhibit a more pronounced increase in leaf photosynthesis under elevated CO2 than lowland plants. In order to test whether this higher carbon fixation efficiency will translate into increased biomass production under CO2 enrichment we exposed plots of narrow alpine grassland (Swiss Central Alps, 2470 m) to ambient (355 mu l l(-1)) and elevated (680 mu l l(-1)) CO2 concentration using open top chambers. Part of the plots received moderate mineral nutrient additions (40 kg ha(-1) year(-1) of nitrogen in a complete fertilizer mix). Under natural nutrient supply CO2 enrichment had no effect on biomass production per unit land area during any of the three seasons studied so far. Correspondingly, the dominant species Carex curvula and Leontodon helveticus as well as Trifolium alpinum did not show a growth response either at the population level or at the shoot level. However, the subdominant generalistic species Poa alpina strongly increased shoot growth (+47%). Annual root production (in ingrowth cores) was significantly enhanced in C. curvula in the 2nd and 3rd year of investigation (+43%) but was not altered in the bulk samples for all species. Fertilizer addition generally stimulated above-ground (+48%) and below-ground (+26%) biomass production right from the beginning. Annual variations in weather conditions during summer also strongly influenced above-ground biomass production (19-27% more biomass in warm seasons compared to cool seasons). However, neither nutrient availability nor climate had a significant effect on the CO2 response of the plants. Our results do not support the hypothesis that alpine plants, due to their higher carbon uptake efficiency, will increase biomass production under future atmospheric CO2 enrichment, at least not in such late successional communities. However, as indicated by the response of P. alpina, species-specific responses occur which may lead to altered community structure and perhaps ecosystem functioning in the long-term. Our findings further suggest that possible climatic changes are likely to have a greater impact on plant growth in alpine environments than the direct stimulation of photosynthesis by CO2. Counter-intuitively, our results suggest that even under moderate climate warming or enhanced atmospheric nitrogen deposition positive biomass responses to CO2 enrichment of the currently dominating species are unlikely.

KEYWORDS: AMBIENT, ATMOSPHERIC CARBON-DIOXIDE, BALANCE, NITROGEN, PLANT GROWTH, TEMPERATURE, TUSSOCK TUNDRA, WHITE CLOVER

2143

Schappi, B., and C. Korner. 1997. In situ effects of elevated CO2 on the carbon and nitrogen status of alpine plants. *Functional Ecology 11(3):290-299.*

1. The effect of elevated CO2 on tissue composition in an alpine grassland (Swiss Central Alps, 2500m) under both natural and increased nutrient supply (NPK) is summarized. 2. During 3 years of CO2 enrichment the concentration of total non- structural carbohydrates (TNC) in leaves increased by 32% in Leontodon helveticus (largely sugar) and by 56% in Trifolium alpinum (largely starch) but did not

change significantly in the dominant sedge Carex curvula and in Poa alpina, currently a rare species at this site. 3. Enhanced mineral nutrient supply (unlike elevated CO2) greatly stimulated growth but did not reduce the CO2-induced TNC accumulation, 4. Under elevated CO2 nitrogen concentrations (per g TNC-free dry matter) of green leaves decreased in Leontodon (-21%) and in Trifolium (-24%) but not or only slightly in Carer and in Pea. NPK addition compensated this CO2 effect an nitrogen concentration in Trifolium bur not in the other species. 5. In below-ground tissue neither TNC nor nitrogen concentration responded to CO2 fertilization. 6. The nitrogen pool per unit land area at peak season biomass remained unaffected by the CO2 treatment. 7. Overall our results suggest that the late successional dominant sedge Carex curvula remains unaffected by elevated CO2, independently of mineral nutrient supply, whereas the co- dominant and sub-dominant forbs Leontodon helveticus and Trifolium alpinum show both an increase of TNC as well as N depletion under elevated CO2. 8. None of these changes in active plant tissue translate into compositional changes in naturally senesced litter suggesting caution with predictions of CO2 effects on decomposition based on data from green plant material.

KEYWORDS: ACCUMULATION, ATMOSPHERIC CO2, DIOXIDE, ESTUARINE MARSH, GROWTH, HIGH- ALTITUDES, LONG-TERM EXPOSURE, LOW-TEMPERATURE, PHOTOSYNTHETIC INHIBITION, TUSSOCK TUNDRA

2144

Schenk, U., H.J. Jager, and H.J. Weigel. 1996. Nitrogen supply determines responses of yield and biomass partitioning of perennial ryegrass to elevated atmospheric carbon dioxide concentrations. *Journal of Plant Nutrition 19(10-11):1423-1440.*

Perennial ryegrass (Lolium perenne L. cv. Parcour) grown at eight levels of nitrogen (N) fertilization (0-765 mg/pot) was exposed to ambient (390 ppm) and elevated (690 ppm) carbon dioxide (CO2) concentrations for 83 days. Plants were cut three times and dry matter yields determined for each harvest. At final harvest, dry weight of root and stubble biomass was determined, as N concentrations of all plant fractions were determined. Carbon dioxide enrichment effects on yield and total plant biomass increased with increasing N fertilization. The weaker CO2-related yield enhancement at low N supply was due to the plants inability to increase tiller number. Root fraction of total plant biomass at final harvest was increased by high CO2 and decreased by N supply. Root biomass was significantly increased by CO2 enrichment and for both CO2 treatments the N supply for maximum root mass coincided with the N supply for reaching maximum total plant biomass. A significant correlation between root fraction of total plant dry matter and N concentration of total plant biomass, which was not changed by CO2 enrichment, indicates that biomass partitioning between shoot and root is controlled by the internal N status of the plant.

KEYWORDS: CO2- ENRICHMENT, GRASSLANDS, GROWTH-RESPONSE, MOBILIZATION, PLANT-RESPONSES, ROOTS, SOIL, STORAGE, STUBBLE, WHITE CLOVER

2145

Schenk, U., H.J. Jager, and H.J. Weigel. 1997. The response of perennial ryegrass white clover mini-swards to elevated atmospheric CO2 concentrations: effects on yield and fodder quality. *Grass and Forage Science 52(3):232-241.*

In order to assess the effects of future elevated atmospheric CO2 concentrations on yield, mineral content and the nutritive value of mixed swards of perennial ryegrass (Lolium perenne L.) and white clover (Trifolium repens L.). both species were grown as monocultures and as different mixtures and were exposed season-long to ambient (380 p.p.m.) and elevated (670 p.p.m.) CO2 concentrations in open-top chambers. Mini-swards were cut four times at about monthly intervals at a height of 5 cm, dry- matter yields were determined and content of macroelements (N, P, K, S, Mg, Ca, Na) and crude fibre, crude protein and ash content were measured. The CO2-related increase in seasonal yield amounted to 16-38% for white clover monocultures, 12-29% for mixed swards and 5-9% for ryegrass monocultures. The white clover content of all swards was significantly enhanced by elevated CO2. The K and Na content of total yield was decreased by high CO2 but did not fall below the minimum requirements for ruminants. As the Ca content of total yield was increased by elevated CO2 and the P content was not changed, the Ca/P ratio of total yield was increased and exceeded values required for animal nutrition. The crude protein content of total yield was reduced by high CO2 at thr beginning of the growing season only and was increased by elevated CO2 in the course of the experiment, whereas crude fibre content was decreased through out the season, sometimes falling below the minimum requirement for ruminants. Removal of N, P, S, Mg and Ca by cutting was significantly enhanced because of CO2 enrichment, The results show that, besides the positive effect of rising atmospheric CO2 on dry-matter yield of white clover/ryegrass swards, impacts on the nutritive value should be expected. Possible changes in species composition and implications for grassland management are briefly discussed.

KEYWORDS: CARBON DIOXIDE, CLIMATE CHANGE, ENRICHMENT, GROWTH-RESPONSE, LOLIUM-PERENNE, NITROGEN, PASTURE TURVES, PLANT-RESPONSES, SIMULATED SEASONAL-CHANGES, TRIFOLIUM- REPENS

2146

Schenk, U., H.J. Jager, and H.J. Weigel. 1997. The response of perennial ryegrass/white clover swards to elevated atmospheric CO2 concentrations .1. Effects on competition and species composition and interaction with N supply. *New Phytologist 135(1):67-79.*

The effects of long-term carbon dioxide enrichment on competition for nutrients and light in a ryegrass/clover association were determined for simulated swards of perennial ryegrass (Lolium perenne L. cv. Parcour) and white clover (Trifolium repens L. cv. Karina), which were grown as monocultures and in three mixtures (25/75, 50/50, 75/25), according to the replacement design, at two levels of nitrogen (N) supply (no additional N and 200 kg N ha(-1)) and at season- long ambient (380 ppm) and elevated (670 ppm) CO2 concentrations, in open-top chambers. Stands were cut four times, at about monthly intervals, to a height of 5 cm. Plant material was separated into different species, fresh and dry weights were determined and the content of macroelements (N, P, K, S, Mg) in both species was measured. In addition, plant height of both species at harvest dates and during several regrowth periods was monitored. Results indicate that both species made demand on different resources and profited from growth in a mixed sward. CO2-related yield increase amounted to 16-42% for white clover whereas the effect of high CO2 on ryegrass yield ranged between -33% and +9% depending on N supply, mixture and year. As a result the contribution of white clover to total yield in mixed swards was significantly enhanced by CO2 enrichment at many harvests in both N supply treatments. Without additional N supply, shoot competition for light was intensified by CO2 enrichment to the disadvantage of ryegrass, since clover petioles grew longer and ryegrass was shorter at elevated CO2. With N fertilization, no marked effect of CO2 enrichment on interspecific competition could be observed. Since clover and total yield were increased by CO2 enrichment, nutrient requirements were also increased and potassium deficiency and increased intraspecific competition of clover for K was observed in the mixtures under elevated CO2 which had the highest nutrient withdrawal. Although white clover profited much more from CO2 enrichment in both N fertilization treatments, the suppression of ryegrass in mixed swards could only be observed under low N conditions. Generally, the effect of N fertilization on competitive interference between both species was much greater than the effect of

CO2 enrichment and it is suggested that the effect of elevated CO2 on the balance of species and the outcome of competition in a grass/clover sward is mainly dependent on the N status.

KEYWORDS: CARBON DIOXIDE, GROWTH-RESPONSE, LOLIUM-PERENNE, MINERAL NUTRITION, MODEL-ECOSYSTEMS, PASTURE TURVES, PLANT-RESPONSES, SIMULATED SEASONAL-CHANGES, TRIFOLIUM-REPENS L, WHITE CLOVER

2147

Schenk, U., R. Manderscheid, J. Hugen, and H.J. Weigel. 1995. Effects of co2 enrichment and intraspecific competition on biomass partitioning, nitrogen-content and microbial biomass carbon in soil of perennial ryegrass and white clover. *Journal of Experimental Botany 46(289):987-993.*

Seedlings of perennial ryegrass (Lolium perenne L. cv. Parcour) and white clover (Trifolium repens L. cv. Karina) grown at five different plant densities were exposed to ambient (390 ppm) and elevated (690 ppm) CO2 concentrations, After 43 d the effects of CO2 enrichment and plant density on growth of shoot and root, nitrogen concentration of tissue, and microbial biomass carbon (C-mic) in soil were determined, CO2 enrichment of Lolium perenne increased shoot growth on average by 17% independent of plant density, while effects on root biomass ranged between -4% and +107% due to an interaction with plant density, Since tiller number per plant was unaffected by elevated CO2, the small response of shoot growth to CO2 enrichment was attributed to low sink strength. A significant correlation between nitrogen concentration of total plant biomass and root fraction of total plant dry matter, which was not changed by CO2 enrichment, indicates that nitrogen status of the plant controls biomass partitioning and the effect of CO2 enrichment on root growth. Effects of elevated CO2( )and plant density on shoot and root growth of Trifolium repens were not significantly interacting and mean CO2 related increase amounted to 29% and 66%, respectively, However, growth enhancement due to elevated CO2 was strongest when leaf area index was lowest. Total amounts of nitrogen in shoots and roots were bigger at 690 ppm than at 390 ppm CO2. There was a significant increase in C-mic in experiments with both species whereas plant density had no substantial effect.

KEYWORDS: DIOXIDE CONCENTRATION, ELEVATED ATMOSPHERIC CO2, ENVIRONMENTS, GROWTH, LEAF, PHOTOSYNTHESIS, PLANT, RESPIRATION, TEMPERATURE, TRIFOLIUM- REPENS

2148

Scherzer, A.J., J. Rebbeck, and R.E.J. Boerner. 1998. Foliar nitrogen dynamics and decomposition of yellow-poplar and eastern white pine during four seasons of exposure to elevated ozone and carbon dioxide. *Forest Ecology and Management 109(1-3):355-366.*

Yellow-poplar (Liriodendron tulipifera L.) and eastern white pine (Pinus strobus L.) seedlings growing in two plantations were fumigated from 1992 to 1995 in open-top chambers with charcoal-filtered air (CF), ambient air (chamberless), one time ambient ozone (1X), twice ambient ozone (2X), or twice ambient ozone+twice ambient CO2 (2X+CO2). Across all treatments and years, concentrations of foliar nitrogen (N) in yellow-poplar averaged 26.3 mg g(-1) in June and decreased to 13.8 mg g(-1) just prior to leaf senescence. While leaves from all treatments exhibited similar seasonal reductions, actual N concentrations were greatly affected by treatment. Ozone (O-3) alone did not significantly alter foliar N concentrations; however, 2X+CO2 decreased N concentrations by 18-40% depending on time of sampling. After one season of fumigation, 2X+CO2-exposed leaves of yellow-poplar decayed significantly more slowly than leaves from all other treatments. In contrast, white pine needles demonstrated few differences in N concentrations or decomposition during the first 3 years of fumigation. By the forth season, 2X-CO2-air significantly reduced N concentrations of current year needles. In needles grown in CF air N concentrations ranged from 14.8 mg g(-1) in June to 17.2 mg g(- 1) in October. 2X+CO2-air reduced N levels in white pine by 10- 23% depending on time of sampling. For both species, significant differences in N due to leaf age and canopy position must be taken into consideration when evaluating the data. Our experiments indicate that elevated CO2 in the presence of elevated O-3 can reduce foliar N concentrations and reduce litter decay, thus affecting nutrient cycling. (C) 1998 Elsevier Science B.V.

KEYWORDS: CLIMATE CHANGE, CO2, FIELD, GROWTH, L SEEDLINGS, LEAF LITTER, NUTRITION, PLANTS, SIMULATED ACID-RAIN, SPRUCE PICEA-ABIES

2149

Schier, G.A., and C.J. McQuattie. 1998. Effects of carbon dioxide enrichment on response of mycorrhizal pitch pine (Pinus rigida) to aluminum: growth and mineral nutrition. *Trees-Structure and Function 12(6):340-346.*

Carbon dioxide enrichment may increase the Al tolerance of trees by increasing root growth, root exudation and/or mycorrhizal colonization. The effect of elevated CO2 on the response of mycorrhizal pitch pine (Pinus rigida Mill.) seedlings to Al was determined in two experiments with different levels of nutrients, 0.1- or 0.2-strength Clark solution. During each experiment, seedlings inoculated with the ectomycorrhizal fungus Pisolithus tinctorius (Pers.) Coker & Couch were grown 13 weeks in sand irrigated with nutrient solution (pH 3.8) containing 0, 6.25, 12.5, or 25 mg/l Al (0, 232, 463, or 927 mu M Al) in growth chambers fumigated with 350 (ambient) or 700 (elevated) mu l/l CO2. At ambient CO2 in the absence of Al, mean total dry weights (DW) of seedlings at the high nutrient level were 164% higher than those at the low level. Total DW at elevated CO2, in the absence of Al, was significantly greater than that in ambient CO2 at the low (+34%) and high (+16%) nutrient levels. Root and shoot DW at both nutrient levels decreased with increasing Al concentrations with Al reducing root growth more than shoot growth. Although visible symptoms of Al toxicity in roots and needles were reduced by CO2 enrichment, there were no significant CO2 x Al interactions for shoot or root DW. The percentage of seedling roots that became mycorrhizal was negatively related to nutrient level and was greater at elevated than at ambient CO2 levels. Generally, elevated CO2 had little effect on concentration of mineral nutrients in roots and needles. Aluminum reduced concentrations of most nutrients by inhibiting uptake.

KEYWORDS: ATMOSPHERIC CO2 ENRICHMENT, COLONIZATION, ELEVATED CO2, NUTRIENT, PHOSPHORUS, PICEA-RUBENS, QUERCUS-ALBA, ROOTS, SEEDLING GROWTH, SOIL N

2150

Schimel, D.S. 1995. Terrestrial biogeochemical cycles - global estimates with remote-sensing. *Remote Sensing of Environment 51(1):49-56.*

The carbon rand nitrogen cycles are crucial for understanding the changing Earth system, influencing atmospheric concentrations of greenhouse gases, primary productivity of the biosphere, and biogenic emissions of reactive trace species. The carbon budget of the terrestrial biosphere has attracted special attention because of its role in atmospheric changes in carbon dioxide. The terrestrial biosphere influences atmospheric CO2 through three main modes: First, large, nearly balanced fluxes of CO2 in photosynthesis and respiration exhibit a degree of interannual variability which can influence atmospheric CO2, at feast on annual to decadal time scales. Second, land use changes release CO2 to the atmosphere. Third, poorly understood processes are

likely resulting in enhanced uptake of CO2 in certain ecosystems, acting as a sink in the global carbon cycle. This sink may result from forest demographics, atmospheric N deposition, or direct CO2 fertilizatian, or some synergistic combination of those processes. Global estimates of terrestrial carbon cycle components requires the use of remote observations; however, the appropriate remote sensing strategies are quite different for the various components.

KEYWORDS: ATMOSPHERIC CO2, BIOSPHERE, CARBON DIOXIDE, FOREST ECOSYSTEMS, HIGH-RESOLUTION RADIOMETER, MODEL, NITROGEN, PHOTOSYNTHESIS, STOMATAL CONDUCTANCE, TALLGRASS PRAIRIE

2151

Schimel, D.S. 1995. Terrestrial ecosystems and the carbon-cycle. *Global Change Biology 1(1):77-91.*

The terrestrial biosphere plays an important role in the global carbon cycle. In the 1994 Intergovernmental Panel Assessment on Climate Change (IPCC), an effort was made to improve the quantification of terrestrial exchanges and potential feedbacks from climate, changing CO2, and other factors; this paper presents the key results from that assessment, together with expanded discussion. The carbon cycle is the fluxes of carbon among four main reservoirs: fossil carbon, the atmosphere, the oceans, and the terrestrial biosphere. Emissions of fossil carbon during the 1980s averaged 5.5 Gt y(-1). During the same period, the atmosphere gained 3.2 Gt C y(-1), and the oceans are believed to have absorbed 2.0 Gt C y(-1). The regrowing forests of the Northern Hemisphere may have absorbed 0.5 Gt C y(-1) during this period. Meanwhile, tropical deforestation is thought to have released an average 1.6 Gt C y(-1) over the 1980s. While the fluxes among the four pools should balance, the average 1980s values lead to a 'missing sink' of 1.4 Gt C y(-1). Several processes, including forest regrowth, CO2 fertilization of plant growth (c. 1.0 Gt C y(-1)), N deposition (c. 0.6 Gt C y(-1)), and their interactions, may account for the budget imbalance. However, it remains difficult to quantify the influences of these separate but interactive processes. Uncertainties in the individual numbers are large, and are themselves poorly quantified. This paper presents detail beyond the IPCC assessment on procedures used to approximate the flux uncertainties. Lack of knowledge about positive and negative feedbacks from the biosphere is a major limiting factor to credible simulations of future atmospheric CO2 concentrations. Analyses of the atmospheric gradients of CO2 and (CO2)-C-13 concentrations provide increasingly strong evidence for terrestrial sinks, potentially distributed between Northern Hemisphere and tropical regions, but conclusive detection in direct biomass and soil measurements remains elusive. Current regional-to-global terrestrial ecosystem models with coupled carbon and nitrogen cycles represent the effects of CO2 fertilization differently, but all suggest long-term responses to CO2 that are substantially smaller than potential leaf- or laboratory whole plant-level responses. Analyses of emissions and biogeochemical fluxes consistent with eventual stabilization of atmospheric CO2 concentrations are sensitive to the way in which biospheric feedbacks are modeled by c. 15%. Decisions about land use can have effects of 100s of Gt C over the next few centuries, with similarly significant effects on the atmosphere. Critical areas for future research are continued measurements and analyses of atmospheric data (CO2 and (CO2)-C-13) to serve as large-scale constraints, process studies of the scaling from the photosynthetic response to CO2 to whole-ecosystem carbon storage, and rigorous quantification of the effects of changing land use on carbon storage.

KEYWORDS: ATMOSPHERIC CARBON, BIOMASS, DIOXIDE, ELEVATED CO2, FOREST ECOSYSTEMS, GLOBAL CLIMATE-CHANGE, GROWTH-RESPONSE, NITROGEN DEPOSITION, STORAGE, TREE GROWTH

2152

Schindler, D.W., and S.E. Bayley. 1993. The biosphere as an increasing sink for atmospheric carbon - estimates from increased nitrogen deposition. *Global Biogeochemical Cycles 7(4):717-733.*

Estimates of carbon uptake and storage based on global nitrogen deposition, C:N ratios for typical terrestrial ecosystems, and recent ecosystem-scale nutrient studies indicate that 1.0-2.3 Gt C yr-1 of carbon storage may be stimulated by anthropogenically caused increases in nitrogen deposition in the past century. Sixty four to eighty four percent of global nitrogen uptake appears to occur on northern continents, with the remainder largely in northern coastal oceans. Increased nitrogen input by terrestrial ecosystems causes increased accumulation of carbon as plant tissue, with C:N ratios generally 50 to 200:1. Calculations suggest that northern continents are a major sink for carbon and that nitrogen- stimulated carbon uptake may more or less balance global carbon losses to the atmosphere from deforestation and agriculture. Much of the uptake appears to occur in aggrading forests, and the question of how long it can continue has important consequences for global carbon budgets.

KEYWORDS: ACIDIFICATION, BUDGET, CO2, CYCLE, DECOMPOSITION, ECOSYSTEMS, FOREST, GLOBAL CHANGE, OCEANIC UPTAKE, SPHAGNUM

2153

Schlesinger, W.H. 1993. Response of the terrestrial biosphere to global climate change and human perturbation. *Vegetatio 104:295-305.*

Despite 20 years of intensive effort to understand the global carbon cycle, the budget for carbon dioxide in the atmosphere is unbalanced. To explain why atmospheric CO2 is not increasing as rapidly as it should be, various workers have suggested that land vegetation acts as a sink for carbon dioxide. Here, I examine various possibilities and find that the evidence for a sink of sufficient magnitude on land is poor. Moreover, it is unlikely that the land vegetation will act as a sink in the postulated warmer global climates of the future. In response to rapid human population growth, destruction of natural ecosystems in the tropics remains a large net source of CO2 for the atmosphere, which is only partially compensated by the potential for carbon storage in temperate and boreal regions. Direct and inadvertent human effects on land vegetation might increase the magnitude of regional CO2 storage on land, but they are unlikely to play a significant role in moderating the potential rate of greenhouse warming in the future.

KEYWORDS: ATMOSPHERIC CARBON-DIOXIDE, ELEVATED CO2, FOREST ECOSYSTEMS, LAND-USE, NITROGEN, NO-TILLAGE, ORGANIC-CARBON, SOIL PROPERTIES, STORAGE, TUSSOCK TUNDRA

2154

Schmid, R., R. Forster, and M.J. Dring. 1992. Circadian-rhythm and fast responses to blue-light of photosynthesis in ectocarpus (phaeophyta, ectocarpales) .2. Light and co2 dependence of photosynthesis. *Planta 187(1):60-66.*

Photosynthesis of Ectocarpus siliculosus (Dillwyn) Lyngb. under continuous saturating red irradiation follows a circadian rhythm. Blue-light pulses rapidly stimulate photosynthesis with high effectiveness in the troughs of this rhythm but the effectiveness of such pulses is much lower at its peaks. In an attempt to understand how blue light and the rhythm affected photosynthesis, the effects of inorganic carbon on photosynthetic light saturation curves were studied under different irradiation conditions. The circadian rhythm of photosynthesis was apparent only at irradiances which were not limiting for photosynthesis. The same was found for blue- light-stimulated photosynthesis, although

stimulation was observed also under very low red-light irradiances after a period of adaptation, provided that the inorganic-carbon concentration was not in excess. Double-reciprocal plots of light-saturated photosynthetic rates versus the concentration of total inorganic carbon (up to 10 mM total inorganic carbon) were linear and had a common constant for half-saturation (3.6 mM at pH 8) at both the troughs and the peaks of the rhythm and before and after blue-light pulses. Only at very low carbon concentrations was a clear deviation found from these lines for photosynthesis at the rhythm maxima (red and blue light), which indicated that the strong carbon limitation specifically affected photosynthesis at the peak phases of the rhythm. Very high inorganic carbon concentrations (20 mM) in the medium diminished the responses to blue light, although they did not fully abolish them. The kinetics of the stimulation indicate that the rate of photosynthesis is affected by two blue-light- dependent components with different time courses of induction and decay. The faster component seemed to be at least partially suppressed at red-light irradiances which were not saturating for photosynthesis. Lowering the pH of the medium had the same effects as an increase of the carbon concentration to levels of approx. 10 mM. This indicates that Ectocarpus takes up free CO2 only and not bicarbonate, although additional physiological mechanisms may enhance the availability of CO2.

KEYWORDS: CHLAMYDOMONAS-SEGNIS, DIOXIDE, INORGANIC CARBON-SOURCES

2155
Schmitt, V., A. Kussmaul, and A. Wild. 1999. Interaction of elevated CO2 and ozone concentrations and irrigation regimes on leaf anatomy and carbohydrate status of young oak (Quercus petraea) trees. *Zeitschrift Fur Naturforschung C-A Journal of Biosciences 54(9-10):812-823.*

Young sessile oak (Quercus petraea) trees were exposed for one vegetation period in closed environmental chambers in a crossed factorial study on effects to varied CO2 concentrations, ozone concentrations and irrigation treatments. Elevated CO2 concentrations (ambient + 350 mu mol mol(-1)) caused a significant increase in biomass production, alterations in leaf anatomy and chloroplast ultrastructure as well as an increase in leaf starch content, as compared to ambient CO2 concentrations. The effects of elevated O-3 concentrations and drought stress were far less distinct. The leaf starch content was influenced by CO2 and O-3 in a synergistic manner.

KEYWORDS: ACCLIMATION, ATMOSPHERIC CO2, CARBON DIOXIDE, ENRICHMENT, GROWTH, LEAVES, PLANTS, SOURCE-SINK RELATIONS, STARCH, ULTRASTRUCTURE

2156
Schneider, S.H., and T.L. Root. 1996. Ecological implications of climate change will include surprises. *Biodiversity and Conservation 5(9):1109-1119.*

In addition to assessing the impacts of CO2 doubling on environment and society, more consideration is needed to estimate extreme events or 'surprises'. This is particularly important at the intersection of disciplines like climate and ecology because the potential for large discontinuities is high given all the possible climate/biota interactions. The vast disparities in scales encountered by those working in traditional ecology (typically 20 m) and climatology (typically 200 km) make diagnoses of such interactions difficult, but these can be addressed by an emerging research paradigm we call strategic cyclical scaling (SCS). The need to anticipate outlier events and assign them subjective probabilities suggests emphasis on interdisciplinary research associations. The desire to reduce societal vulnerability to such events suggests the need to build adaptive management and diverse economic activities into social organizations. The effectiveness of adaptation responses to anticipated climatic changes is complicated when consideration of transient changes, regional disturbances, large unforseeable natural fluctuations and surprises are considered. Slowing down the rate of disturbances and decreasing vulnerability are advocated as the most prudent responses to the prospect of human-induced climatic changes.

KEYWORDS: CO2, SCALE

2157
Scholes, M.C., D. Powlson, and G.L. Tian. 1997. Input control of organic matter dynamics. *Geoderma 79(1-4):25-47.*

The amount and quality of inputs into soil organic matter will be altered by both climate and landuse change. The increase in growth of plants caused by increasing CO2 concentration implies not only potential increases in yields but also increases in plant residues. Simulation models using doubled CO2 levels predict global net primary productivity (NPP) to increase by 16.3%, over half of which will occur in the tropics. For tropical ecosystems increases in NPP will be dominated by the effects of elevated CO2, with water and nitrogen availability and temperature playing a less significant role. Phosphorus limitation may determine whether the potential for increased plant growth will be realized. The distribution of C3 and C4 species in the tropics could be affected by landuse change and estimates of yield increases will be dependent on their proportions. The allocation of photosynthate to the root will increase under elevated CO2, resulting in increased fine root dry weight and root length. Root sink strength and the turnover of roots and associated symbionts are critical knowledge gaps. Carbon:nitrogen ratios in tissues will increase resulting in decreased decomposition rates. The concentration of secondary compounds will be affected more by nitrogen limitations than a direct CO2 effect. Changes in lignin, tannin and polyphenol levels are more important in the decomposability of tropical liners than changes in the C:N ratios. Decomposition models will have to be altered to take into account changes in plant composition. The role of models in predicting the effects of management practice on long-term fertility is addressed. (C) 1997 Elsevier Science B.V.

KEYWORDS: ATMOSPHERIC CO2 ENRICHMENT, C-13 NATURAL ABUNDANCE, CHEMICAL-COMPOSITION, ELEVATED CARBON-DIOXIDE, NITROGEN MINERALIZATION, NUTRIENT RELEASE, ROOT-GROWTH, SIZE-FRACTIONS, SOIL MICROBIAL BIOMASS, TROPICAL CONDITIONS

2158
Scholes, R.J., and N. vanBreemen. 1997. The effects of global change on tropical ecosystems. *Geoderma 79(1-4):9-24.*

Alteration of land use will continue to be the dominant driver of environmental change in the tropics for the next several decades. It can take the form of fundamental vegetation cover transformation, or of intensification of existing land use without substantial change in cover type. Atmospheric composition changes and resultant climate changes could become ecologically significant within the next century. Changes in atmospheric composition in the tropics are essentially the same as those in higher latitudes, despite differences in the source and sink strengths for trace gases. Such changes can affect the functioning of tropical ecosystems through several processes, principally those related to carbon and nutrient assimilation and their interactions. Atmospheric composition may also have an indirect affect on tropical ecosystems via its effects on the climate. Predicted temperature increases in the tropics are less extreme than at high latitudes, but could still be biologically significant, especially at the tropical margins. The structure and productivity of ecosystems of the subhumid and dry tropics are very sensitive to changes in water balance, which could be caused by a combination of changes in precipitation and temperature. It is presently not possible to predict rainfall changes at ecologically meaningful scales

with any confidence. (C) 1997 Elsevier Science B.V.

KEYWORDS: ATMOSPHERIC CARBON-DIOXIDE, CLIMATE, CO2, DECOMPOSITION, DEFORESTATION, GRASSLANDS, MODEL, NITROGEN, SOIL ORGANIC MATTER, TURNOVER

2159

Schortemeyer, M., O.K. Atkin, N. McFarlane, and J.R. Evans. 1999. The impact of elevated atmospheric CO2 and nitrate supply on growth, biomass allocation, nitrogen partitioning and N-2 fixation of Acacia melanoxylon. *Australian Journal of Plant Physiology 26(8):737-747.*

The interactive effects of nitrate supply and atmospheric CO2 concentration on growth, N-2 fixation, dry matter and nitrogen partitioning in the leguminous tree Acacia melanoxylon R. Br. were studied. Seedlings were grown hydroponically in controlled-environment cabinets for 5 weeks at seven N-15- labelled nitrate levels, ranging from 3 to 6400 mmol m(-3). Plants were exposed to ambient (similar to 350 mu mol mol(-1)) or elevated (similar to 700 mu mol mol(-1)) atmospheric CO2 for 6 weeks. Total plant dry mass increased strongly with nitrate supply. The proportion of nitrogen derived from air decreased with increasing nitrate supply. Plants grown under either ambient or elevated CO2 fixed the same amount of nitrogen per unit nodule dry mass (16.6 mmol N per g nodule dry mass) regardless of the nitrogen treatment. CO2 concentration had no effect on the relative contribution of N2 fixation to the nitrogen yield of plants. Plants grown with greater than or equal to 50 mmol m(-3) N and elevated CO2 had approximately twice the dry mass of those grown with ambient CO2 after 42 days. The rates of net CO2 assimilation under growth conditions were higher per unit leaf area for plants grown under elevated CO2. Elevated CO2 also decreased specific foliage area, due to an increase in foliage thickness and density. Dry matter partitioning between plant organs was affected by ontogeny and nitrogen status of the plants, but not by CO2 concentration. In contrast, plants grown under elevated CO2 partitioned more of their nitrogen to roots. This could be attributed to reduced nitrogen concentrations in foliage grown under elevated CO2.

KEYWORDS: ALNUS-GLUTINOSA, CARBON DIOXIDE, DYNAMICS, ECOSYSTEMS, ENRICHMENT, GAS-EXCHANGE, MODULATION, PLANTAGO-MAJOR, SEEDLINGS, TRIFOLIUM-REPENS L

2160

Schortemeyer, M., U.A. Hartwig, G.R. Hendrey, and M.J. Sadowsky. 1996. Microbial community changes in the rhizospheres of white clover and perennial ryegrass exposed to free air carbon dioxide enrichment (FACE). *Soil Biology and Biochemistry 28(12):1717-1724.*

Increases in the global atmospheric concentration of CO2 will not only directly affect the growth of plants, but might also alter the living conditions for soil biota. This could lead to shifts in the size and composition of the soil microbial communities. In this study we investigated the response of heterotrophic bacteria, NH4+-oxidising bacteria, and Rhizobium leguminosarum by. trifolii populations to elevated atmospheric CO2 concentrations in a model field-scale grassland ecosystem. The Free Air CO2 Enrichment (FACE) facility in Eschikon, Switzerland, releases CO2-enriched air into three large circular areas, each of 18 m dia, to a final CO2 concentration of 600 mu mol mol(-1), while three control areas of the same size receive ambient CO2 concentrations (similar to 350 mu mol mol(-1)). For this study, white clover (Trifolium repens L.) and perennial ryegrass (Lolium perenne L.) were grown as replicated monocultures within the FACE rings. Soil samples were taken from 0-10 cm depth in May and November 1994 (the second year of CO2-enrichment), and rhizosphere soil was obtained from clover and ryegrass roots for enumeration of bacteria. While the total numbers of culturable heterotrophic bacteria (determined by plate counts) in the rhizospheres of both plant species were little affected by CO2-enrichment, the populations of R. leguminosarum by. trifolii (enumerated by MPN) were increased two-fold in the rhizospheres of white clover exposed to elevated atmospheric CO2. There was no effect of the CO2 concentration on the populations of R. leguminosarum by. trifolii in the rhizospheres of perennial ryegrass, indicating that the increase of Rhizobium numbers is a host-related response to elevated atmospheric CO2. The numbers of autotrophic NH4+-oxidizing bacteria in the rhizospheres (enumerated by MPN) were unaffected by the atmospheric CO2 concentration. There was also no effect of the CO2 concentration on the amount of microbial biomass C in the bulk, non-rhizosphere soils in white clover or perennial ryegrass plots. These data indicate that under a legume crop, at least in terms of inoculum quality in the rhizosphere soil, symbiotic nitrogen-fixing organisms might be favoured by elevated atmospheric CO2 concentrations. (C) 1997 Elsevier Science Ltd.

KEYWORDS: ATMOSPHERIC CO2 ENRICHMENT, BIOMASS-C, COMPETITION, DECOMPOSITION, ELEVATED CO2, GROWTH, HETEROTROPHIC BACTERIA, LEGUMES, RESPONSES, ROOT

2161

Schrope, M.K., J.P. Chanton, L.H. Allen, and J.T. Baker. 1999. Effect of CO2 enrichment and elevated temperature on methane emissions from rice, Oryza sativa. *Global Change Biology 5(5):587-599.*

Methane emissions from rice grown within Temperature Gradient Greenhouse Tunnels under doubled CO2 concentrations were 10-45 times less than emissions from control plants grown under ambient CO2. For two cultivars of rice (cvs. Lemont and IR-72), methane emissions increased with a temperature increase of 2 degrees, from outdoor ambient temperatures to the first cell of the ambient CO2 tunnel (ambient temperature + 2 degrees C). Within both tunnels and for both cultivars methane emissions decreased with further temperature increases (from 2 degrees to 5 degrees C above ambient). Carbon dioxide enrichment stimulated both above- and below-ground production. Our original hypothesis was that increased CO2 would stimulate plant productivity and therefore stimulate methane emission, since direct linkages between these parameters have been observed. We hypothesize that CO2 enrichment led to the attenuation of methane production due to increased delivery of oxygen to the rhizosphere because of increased root biomass and porosity. The increased root biomass due to elevated CO2 may have more effectively aerated the soil, suppressing methane production. However, this study may be unique because the low organic content (<1%) of the sandy soils in which the rice was grown created very little oxygen demand.

KEYWORDS: ATMOSPHERIC METHANE, BACTERIA, CARBON DIOXIDE, EXCHANGE, GROWTH RATE, METHANOGENESIS, METHYL-FLUORIDE, OXIDATION, SEASONAL-VARIATION, STABLE ISOTOPES

2162

Schulte, M., C. Herschbach, and H. Rennenberg. 1998. Interactive effects of elevated atmospheric CO2, mycorrhization and drought on long-distance transport of reduced sulphur in young pedunculate oak trees (Quercus robur L.). *Plant, Cell and Environment 21(9):917-926.*

Pedunculate oak (Quercus robur L.) was germinated and grown under nutrient non-limiting conditions for a total of 10-15 weeks at ambient CO2 concentration and 1100 mu mol mol(-1) CO2 either in the presence or the absence of the mycorrhizal fungus Laccaria laccata. Half of the oak trees of these treatments were exposed to drought during final growth by suspending the water supply for 21 d. Mycorrhization and elevated atmospheric CO2 each enhanced total plant biomass per tree. Whereas additional biomass accumulation of trees grown under elevated

CO2 was mainly attributed to increased growth of lateral roots, mycorrhization promoted shoot growth. Water deficiency reduced biomass accumulation without affecting relative water content, but this effect was more pronounced in mycorrhizal as compared to non-mycorrhizal trees. Elevated CO2 partially prevented the development of drought stress, as indicated by leaf water potential, but did not counteract the negative effects of water deficiency on growth during the time studied. Enhanced biomass accumulation requires adaption in protein synthesis and, as a consequence, enhanced allocation of reduced sulphur produced in the leaves to growing tissues. Therefore, allocation of reduced sulphur from oak leaves was studied by flap-feeding radiolabelled GSH, the main long-distance transport form of reduced sulphur, to mature oak leaves. Export of radiolabel proceeded almost exclusively in basipetal direction to the roots. The rate of export of radioactivity out of the fed leaves was significantly enhanced under elevated CO2, irrespective of mycorrhization. A higher proportion of the exported GSH was transported to the roots than to basipetal stem sections under elevated CO2 as compared to ambient CO2. Mycorrhization did not affect S-35 export out of the fed leaves, but the distribution of radiolabel between stem and roots was altered in preference of the stem. Trees exposed to drought did not show appreciable export of the S-35 radioactivity fed to the leaves when grown under ambient CO2. Apparently, drought inhibited basipetal transport of reduced sulphur at the level of phloem loading and/or phloem transport. Elevated CO2 seemed to counteract this effect of drought stress to some extent, since higher leaf water potentials and improved S-35 export out of the fed leaves was observed in oak trees exposed to drought and elevated CO2 as compared to trees exposed to drought and ambient CO2.

KEYWORDS: ABIES KARST L, CARBON DIOXIDE, ENRICHMENT, FAGUS-SYLVATICA, GAS-EXCHANGE, GROWTH, PLANTS, SEEDLINGS, SULFUR NUTRITION, WATER-STRESS

2163

Schwanz, P., K.H. Haberle, and A. Polle. 1996. Interactive effects of elevated CO2, ozone and drought stress on the activities of antioxidative enzymes in needles of Norway spruce trees (Picea abies, [L] Karsten) grown with luxurious N- supply. *Journal of Plant Physiology 148(3-4):351-355.*

The aim of the present study was to address the complex interactions of environmental constraints, ozone and drought stress, with elevated atmospheric CO2 on the activities of antioxidative enzymes and soluble protein contents in needles of Norway spruce trees (Picea abies L.). Five-year-old spruce trees were kept from bud break in June until January of the following year in phytochambers under climatic conditions similar to those of a natural site in the Bavarian forest. The trees were well-supplied with nitrogen and exposed to either elevated CO2 (ambient + 200 mu LL(-1)), elevated ozone (80 nLL(-1), from June to October) or to a combination of both factors. Controls were grown with 20 nLL(-1) O-3 and ambient CO2 levels. In each chamber, a subset of trees was subjected to episodical drought stress in summer. Needles from controls investigated in October (summer conditions) and January (winter conditions) showed little seasonal variation of superoxide dismutase (SOD), an approximately 2-fold reduction in catalase (CAT), and a 2-fold increase in guaiacol peroxidase (POD) activity. Exposure to elevated CO2 did not affect the activities of any of these enzymes in October and January, respectively, but caused a significant reduction in soluble protein. Ozone had no significant effect. Drought stress caused memory effects. In January, needles from trees drought-stressed in summer contained higher activities of defence enzymes and soluble protein contents than needles from well-watered trees. Three weeks after the end of a drought episode in summer, needles from spruce trees grown at elevated CO2 contained increased CAT and POD activities as compared to needles from trees grown at ambient CO2. This response was increased, if elevated ozone was present as an additional stress factor. These observations suggest that Norway spruce trees grown under elevated atmospheric CO2 concentrations might better be able to compensate environmental stresses than trees grown at ambient atmospheric CO2 concentrations.

KEYWORDS: GAS-EXCHANGE, PLANTS, SUPEROXIDE-DISMUTASE ACTIVITY

2164

Schwanz, P., B.A. Kimball, S.B. Idso, D.L. Hendrix, and A. Polle. 1996. Antioxidants in sun and shade leaves of sour orange trees (Citrus aurantium) after long-term acclimation to elevated CO2. *Journal of Experimental Botany 47(305):1941-1950.*

Antioxidative systems and the contents of pigments, malondialdehyde, soluble protein, and carbohydrate were investigated in sun- and shade-acclimated leaves of sour orange (Citrus aurantium) trees that had been grown for 7.5 years under ambient and elevated (+300 mu mol mol(-1)) atmospheric CO2 concentrations. Sun-acclimated leaves contained higher ascorbate, glutathione and soluble carbohydrate contents and higher catalase activities than shade-acclimated leaves. The activities of superoxide dismutases, which belonged to the family of Cu/Zn-isozymes, were similar in sun- and shade- acclimated leaves and decreased in response to enhanced CO2. In shade-acclimated leaves, none of the other parameters studied was affected by elevated CO2. In sun-acclimated leaves elevated CO2 caused increases in carbohydrate and ascorbate contents. There was no evidence for enhanced lipid peroxidation as assessed from the determination of the malondialdehyde contents under either conditions.

KEYWORDS: CARBON-DIOXIDE CONCENTRATIONS, CUZN-SUPEROXIDE, GLUTATHIONE-REDUCTASE, HIGH LIGHT, NEEDLES, NORWAY SPRUCE, PHOTOOXIDATIVE STRESS, PICEA-ABIES L, RISING ATMOSPHERIC CO2, SUPEROXIDE-DISMUTASE

2165

Schwanz, P., C. Picon, P. Vivin, E. Dreyer, J.M. Guehl, and A. Polle. 1996. Responses of antioxidative systems to drought stress in pendunculate oak and maritime pine as modulated by elevated CO2. *Plant Physiology 110(2):393-402.*

The aim of the present study was to investigate the effects of an enhanced CO2 concentration alone or in combination with drought stress on antioxidative systems of a deciduous (oak; Quercus robur) and an evergreen (pine; Pious pinaster) tree species. The seedlings were grown for one season in a greenhouse in tunnels supplied with 350 or 700 mu L L(-1) CO2. The experiment was repeated in a second year. Antioxidants, protective enzymes, soluble protein, and pigments showed considerable fluctuations in different years. Elevated CO2 caused significant reductions in the activities of superoxide dismutases in both oak and pine. The activities of ascorbate peroxidase and catalase were also reduced in most cases. The activities of dehydroascorbate reductase, monodehydroaseorbate radical reductase, glutathione reductase, and guaiacol peroxidase were affected little or not at all by elevated CO2. When the trees were subjected to drought stress by withholding water, the activities of antioxidative enzymes decreased in leaves of pine and oak grown at ambient CO2 and increased in plants grown at elevated CO2 concentrations. The present results suggest that growth in elevated CO2 might reduce oxidative stress to which leaf tissues are normally exposed and enhance metabolic flexibility to encounter increased stress by increases in antioxidative capacity.

KEYWORDS: ASCORBATE, CLIMATE CHANGE, GLUTATHIONE, LEAVES, NEEDLES, PHASEOLUS-VULGARIS L, PHOTOSYNTHESIS, PICEA-ABIES L, QUERCUS-ROBUR L, WATER-STRESS

2166
Schwanz, P., and A. Polle. 1998. Antioxidative systems, pigment and protein contents in leaves of adult Mediterranean oak species (Quercus pubescens and Q- ilex) with lifetime exposure to elevated CO2. *New Phytologist 140(3):411-423.*

The aim of the present study was to investigate the effects of elevated CO2 on the antioxidative systems and the contents of pigments, soluble protein and lipid peroxidation in leaves of adult oaks, Quercus pubescens and Quercus ilex, grown at naturally enriched CO2 concentrations. For this purpose, a field study was conducted at two CO2 springs in Central Italy. Measurements of the pre-dawn water potentials indicated less drought stress in trees close to CO2 springs than in those grown at ambient CO2 concentrations. Most leaf constituents investigated showed significant variability between sampling dates, species and sites. The foliar contents of protein and chlorophylls were not affected in trees grown close to the CO2 vents compared with those in ambient conditions. Increases in glutathione and other soluble thiols were observed, but these responses might have been caused by a low pollution of the vents with sulphurous gases. At CO2 vents, glutathione reductase was unaffected, and superoxide dismutase activity was significantly diminished, in both species. Generally, the activities of catalase, guaiacol peroxidase and ascorbate peroxidase as well as the sum of dehydroascorbate and ascorbate were decreased in leaves from trees grown in naturally CO2- enriched environments compared with those grown at ambient CO2 concentrations. The reduction in protective enzymes did not result in increased lipid peroxidation, but increased monodehydroascorbate radical reductase and dehydroascorbate reductase activities found in leaves of Q. pubescens suggest that the smaller pool of ascorbate was subjected to higher turnover rates. These data show that changes in leaf physiology persist, even after lifetime exposure to enhanced atmospheric CO2. The results suggest that the down-regulation of protective systems, which has also previously been found in young trees or seedlings under controlled exposure to elevated CO2 concentrations, might reflect a realistic response of antioxidative defences in mature trees in a future high-CO2 world.

KEYWORDS: ASCORBATE, CARBON DIOXIDE, DROUGHT STRESS, ENHANCED OZONE, ENZYMES, NEEDLES, PICEA-ABIES L, RESPONSES, RISING ATMOSPHERIC CO2, TREES

2167
Schwartz, M.W. 1992. Potential effects of global climate change on the biodiversity of plants. *The Forestry Chronicle 68(4):462-471.*

Climatologists have observed a consistent increase in atmospheric CO2 over the past 30 years. It is predicted that CO2 levels could double the pre-industrial level of 280 ppm by the year 2100, perphaps much earlier. Climate models of doubled atmospheric CO2 predict that mean temperatures will increase between 1.5 and 4.5-degrees-C globally; these temperature changes will be greater at high latitudes. Mid-continental regions will experience lower rainfall. Predictions of species northward range shifts in response to climate change vary from 100 km to over 500 km. Historical evidence of species range movements following the Pleistocene indicate that tree species typically migrated at rates of 10 km to 40 km per century. A simulation model that predicts the migration response of trees through modem fragmented landscapes predicts migration rates much lower than Pleistocene observations. Thus migration response is likely to lag far behind rates of climatic change, potentially threatening narrowly distributed species whose predicted future ranges do not overlap with their current range. Insect pests and microbial pathogens should respond to climatic warming faster than long-lived trees. Predicted increased drought frequency may increase plant stress and thereby increase the frequency of insect outbreaks and disease. Predictions of species responses are complicated by direct effects of increased CO2, such as increased water-use. efficiency. However, response to elevated CO2 vanes among species. Thus, shifts in composition within plant communities are also likely, but are, as yet, unpredictable.

2168
Scurlock, J.M.O., and D.O. Hall. 1998. The global carbon sink: a grassland perspective. *Global Change Biology 4(2):229-233.*

The challenge to identify the biospheric sinks for about half the total carbon emissions from fossil fuels must include a consideration of below-ground ecosystem processes as well as those more easily measured above-ground. Recent studies suggest that tropical grasslands and savannas may contribute more to the 'missing sink' than was previously appreciated, perhaps as much as 0.5 Pg (= 0.5 Gt) carbon per annum. The rapid increase in availability of productivity data facilitated by the Internet will be important for future scaling-up of global change responses, to establish independent lines of evidence about the location and size of carbon sinks.

KEYWORDS: ATMOSPHERIC CO2, CLIMATE CHANGE, CONIFEROUS FORESTS, CYCLE, ECOSYSTEMS, PRODUCTIVITY, SOIL CARBON, STORAGE, TEMPERATE, WORLDWIDE

2169
Seaton, K.A., and D.C. Joyce. 1993. Effects of low-temperature and elevated co2 treatments and of heat-treatments for insect disinfestation on some native- australian cut flowers. *Scientia Horticulturae 56(2):119-133.*

For bioassay insects, 14 days storage at 1-degrees-C was required for 100% kill of adult flour beetles (Tribolium confusum Koch.), and 10 days at 1-degrees-C killed 100% of Mediterranean fruit fly larvae (Ceratitis capitata Wied.). A CO2 enriched atmosphere of between 45% and 60% (11% and 8% O2, respectively) reduced the time required to achieve 100% mortality of these bioassay insects to 7 days at 1-degrees-C. Increasing the CO2 content of the atmosphere to 80% (4% O2) did not further reduce the time to achieve 100% mortality. Vase life of red kangaroo paw (Anigozanthos rufus) was reduced below that of the unstored control after just 3.5 days at 1-degrees- C. Geraldton wax (Chamelaucium uncinatum) cultivar 'Newmarracarra' was similarly affected after 14 days, and acorn banksia (Banksia prionotes) after 28 days. Vase lives of Geraldton wax cultivar 'Newmarracarra' and of red kangaroo paw were not reduced following 7 days storage at 1-degrees-C in 15% CO2, compared with controls stored in air. However, Geraldton wax and red kangaroo paw vase lives were shortened and flower colour was altered after storage for 7 days in 30% CO2 (15% O2). Geraldton wax and red kangaroo paw had no vase lives following storage in 80% CO2 (4% O2) at 1-degrees-C for 3. 5 days. Heat treatments of hot water dips (46-degrees-C for 30 min or 56-degrees-C for 10 min) and vapour heat (66-degrees-C for 10 min) killed 100% of adult flour beetles and Mediterranean fruit fly larvae, but damaged and shortened the vase lives of Geraldton wax and banksia.

KEYWORDS: COLD-STORAGE, INFLORESCENCES TELOPEA-SPECIOSISSIMA, PHYSIOLOGY, PROTEACEAE, QUARANTINE PROCEDURE, VASE LIFE

2170
Seegmuller, S., and H. Rennenberg. 1994. Interactive effects of mycorrhization and elevated carbon- dioxide on growth of young pedunculate oak (quercus-robur L) trees. *Plant and Soil 167(2):325-329.*

Pedunculate oak (Quercus robur L.) was germinated and grown at ambient CO2 level and 650 ppmv CO2 in the presence and absence of the ectomycorrhizal fungus Laccaria laccata for a total of 6 month under

nutrient non-limiting conditions. Mycorrhization and elevated atmospheric CO2 each supported the growth of the trees. Stem height, stem diameter, and dry matter accumulation of pedunculate oak were increased by mycorrhization. Elevated atmospheric CO2 enhanced stem height, stem diameter, fresh weight and dry weight, as well as lateral root formation of the trees. In combination, mycorrhization and elevated atmospheric CO2 had a more than additive, positive effect on tree height and biomass accumulation, and further improved lateral root formation of the trees. From these findings it is suggested that the efficiency of the roots in supporting the growth of the shoot is increased in mycorrhized oak trees at elevated atmospheric CO2.

KEYWORDS: CO2- ENRICHMENT, MINERAL NUTRITION, SEEDLINGS

2171

Seegmuller, S., M. Schulte, C. Herschbach, and H. Rennenberg. 1996. Interactive effects of mycorrhization and elevated atmospheric CO2 on sulphur nutrition of young pedunculate oak (Quercus robur L) trees. *Plant, Cell and Environment 19(4):418-426.*

Pedunculate oak (Quercus robur L.) was germinated and grown at ambient CO2 concentration and 650 mu mol mol(-1) CO2 in the presence and absence of the ectomycorrhizal fungus Laccaria laccata for a total of 22 weeks under non-limiting nutrient conditions. Sulphate uptake, xylem loading and exudation were analysed in excised roots. Despite a relatively high affinity for sulphate (K-M = 1.6 mmol m(-3)), the rates of sulphate uptake by excised lateral roots of mycorrhizal oak trees were low as compared to herbaceous plants. Rates of sulphate uptake were similar in mycorrhizal and non-mycorrhizal roots and were not affected by growth of the trees at elevated CO2. However, the total uptake of sulphate per plant was enhanced by elevated CO2 and further enhanced by elevated CO2 and mycorrhization. Sulphate uptake seemed to be closely correlated with biomass accumulation under the conditions applied. The percentage of the sulphate taken up by mycorrhizal oak roots that was loaded into the xylem was an order of magnitude lower than previously observed for herbaceous plants. The rate of xylem loading was enhanced by mycorrhization and, in roots of mycorrhizal trees only, by growth at elevated CO2. On a whole-plant basis this increase in xylem loading could only partially be explained by the increased growth of the trees. Elevated CO2 and mycorrhization appeared to increase greatly the sulphate supply of the shoot at the level of xylem loading. For all treatments, calculated rates of sulphate exudation were significantly lower than the corresponding rates of xylem loading of sulphate. Radiolabelled sulphate loaded into the xylem therefore seems to be readily diluted by unlabelled sulphate during xylem transport. Allocation of reduced sulphur from oak leaves was studied by flap-feeding radiolabelled GSH to mature oak leaves. The rate of export of radioactivity from the fed leaves was 4.5 times higher in mycorrhizal oak trees grown at elevated CO2 than in those grown at ambient CO2. Export of radiolabel proceeded almost exclusively in a basipetal direction to the roots. From these experiments it can be concluded that, in mycorrhizal oak trees grown at elevated CO2, the transport of sulphate to the shoot is increased at the level of xylem loading to enable increased sulphate reduction in the leaves. Increased sulphate reduction seems to be required for the enhanced allocation of reduced sulphur to the roots which is observed in trees grown at elevated CO2. These changes in sulphate and reduced sulphur allocation may be a prerequisite for the positive effect of elevated CO2 on growth of oak trees previously observed.

KEYWORDS: CELLS, EFFICIENCY, GROWTH, LONG-DISTANCE TRANSPORT, PLANTS, ROOTS, SEEDLINGS, SULFATE TRANSPORT, SULFUR, TRANSLOCATION

2172

Segal, M., P. Alpert, U. Stein, M. Mandel, and M.J. Mitchell. 1994. Some assessments of the potential 2 X co2 climatic effects on water-balance components in the eastern mediterranean. *Climatic Change 27(4):351-371.*

General circulation model (GCM) coarse evaluations of the climatological impact in the Eastern Mediterranean due to global doubling of the atmospheriC CO2 concentration were used as input for a preliminary estimation of modifications in local processes affecting the water balance in this region. It is suggested that: (i) in the 2 x CO2 climate the average regional change of precipitation associated with typical mid-winter cyclonic systems is relatively small, however, it is associated with redistribution of the regional rainfall; (ii) in the elevated terrain in the northern part of the region, daytime snowmelt due to warm air advection may be enhanced, as much as 2.8 cm per day; and (iii) transpiration in the coastal area of the Eastern Mediterranean may increase by approximately 13% of its current level in the summer and somewhat more in the winter.

KEYWORDS: HEAT-STORAGE, LAYER, MODEL, OCEAN, PRECIPITATION, SENSITIVITY

2173

Seginer, I., C. Gary, and M. Tchamitchian. 1994. Optimal temperature regimes for a greenhouse crop with a carbohydrate pool - a modeling study. *Scientia Horticulturae 60(1-2):55-80.*

A simple crop model with two state variables, namely structural biomass and carbohydrate pool, was used to explore the effect of alternative temperature regimes on greenhouse crop production, Assuming a repeated environmental cycle, certain qualitative predictions could be made. (1) The smaller the plants and the higher the light integral and CO2 enrichment, the higher are the temperatures which lead to maximum production. (2) Day temperatures higher than night temperatures usually lead to higher production. On winter days, however, an inverse temperature regime may result in energy saving without loss of production. (3) Temperature variations may often be tolerated, provided that the mean temperature (temperature integral) is maintained at the level appropriate for maximum production. A limited amount of published experimental data was used to fit the model, leading to a satisfactory agreement.

KEYWORDS: ENRICHMENT, GROWTH, LEAVES, LEVEL, RESPIRATION, TOMATO PLANTS, TOMGRO, YIELD

2174

Sehmer, L., V. Fontaine, F. Antoni, and P. Dizengremel. 1998. Effects of ozone and elevated atmospheric carbon dioxide on carbohydrate metabolism of spruce needles. Catabolic and detoxification pathways. *Physiologia Plantarum 102(4):605-611.*

We have studied the effects of ozone, carbon dioxide and ozone combined with carbon dioxide fumigations on catabolic and detoxification pathways in spruce (Picea abies [L.] Karst.) needles. The results obtained showed an increase in the activities of three enzymes involved in the detoxification pathway, superoxide dismutase (SOD, EC 1.15.1.1), ascorbate peroxidase (AscPOD, EC 1.11.1.11) and glutathione reductase (GR, EC 1.6.4.2) when trees were exposed to ozone and to ozone- carbon dioxide treatments. In these two treatments, the fraction of SOD activity due to the chloroplastic isoform was increased (1.5-fold). In the needles of trees exposed to ozone and to ozone-carbon dioxide fumigation, an increase in the activities of glucose-6-phosphate dehydrogenase (G-6-PDH, EC 1.1.1.49) showed that the cell had the capacity to produce more NADPH necessary for the detoxification. Stimulation of other enzymes of catabolic pathways (fumarase [EC 4.2.1.2], phosphofructokinase [PFK, EC 7.1.1] and

phosphoenolpyruvate carboxylase [PEPC, EC 4.1.1.31]), was also observed making it possible for the cell to provide the reducing power necessary for detoxification as well as energy and carbon skeletons involved in the repair processes. When carbon dioxide alone was applied, no effects could be detected on these enzyme activities. However, when carbon dioxide was combined with ozone, the effect of ozone on trees was less than that induced by ozone alone, suggesting that elevated atmospheric carbon dioxide concentrations may to some extent protect plants from ozone injury.

KEYWORDS: AIR- POLLUTANTS, ASSAY, CO2, ENZYMES, HYDROGEN- PEROXIDE, NORWAY SPRUCE, PHOSPHOENOLPYRUVATE CARBOXYLASE, PINE, PLANTS, SUPEROXIDE-DISMUTASE

2175

Seko, Y., and M. Nishimura. 1996. Effect of CO2 and light on survival and growth of rice regenerants grown in vitro on sugar-free medium. *Plant Cell Tissue and Organ Culture 46(3):257-264.*

Rice (Oryza sativa L.) plantlets regenerated from callus (rice regenerants) were grown in vitro during the preparation stage either on a 1/4 strength N6 gellan gum (4 g 1(-1)) medium without sucrose (SFM) or with 30 g 1(-1) sucrose (SCM), and under CO2 concentrations of 0.4, 2, 10, 50 or 100 mmol mol(-1), a photoperiod of 24 h and a photosynthetic photon flux density (PPFD) of 125 mu mol m(-2) s(-1). Rice regenerants were also grown in vitro on SFM or SCM under CO2 concentration of 50 mmol mol(-1), a photoperiod of 12 or 24 h and a PPFD of 80 or 125 mu mol m(-2) s(-1). All rice regenerants grew successfully on SFM under CO2 concentrations of 50 or 100 mmol mol(-1). Increasing the CO2 concentration increased the survival percentage, shoot length and shoot and root dry weights of rice regenerants grown on SFM. Increasing CO2 concentration had no significant effect on the survival or growth of rice regenerants grown on SCM. Survival percentages of rice regenerants grown on SCM were less than 80% for each of the CO2 concentrations. A photoperiod of 24 h under CO2 enrichment improved the survival and growth of rice regenerants grown on SFM, and increased the survival percentage and shoot dry weight of rice regenerants grown on SCM.

KEYWORDS: CARBON DIOXIDE, CULTURE, ENRICHMENT, INVITRO, SUCROSE CONCENTRATION

2176

Seligman, N.G., and T.R. Sinclair. 1995. Global environment change and simulated forage quality of wheat .2. Water and nitrogen stress. *Field Crops Research 40(1):29-37.*

Forage crops are frequently subjected to stress conditions resulting from inadequate supplies of water and N. Because forages grown under these stress conditions constitute an important resource in animal agriculture, this study was undertaken to assess possible changes in the nutritive value and productivity of forage crops as a consequence of global environment change. A relatively simple, mechanistic model of wheat was extended to simulate growth and important determinants of feed quality ([N], leaf:stem, dry matter digestibility) in an annual, temperate climate C-3 forage grass. Weather data for a semiarid region and different levels of applied N were used to examine the response of forage productivity to various levels of water and N availability. Not surprisingly, responses to global environment change were highly dependent on the availability of both water and N. When either resource was available at low levels, production of digestible dry matter was nearly unchanged by elevated [CO2] or increased temperature. When compared at equivalent development stages, small increases in forage quality were simulated, mainly because higher temperature resulted in achievement of the initiation of grain fill at an earlier date. As N availability increased, differences in forage characteristics and productivity became more prominent. Elevated ambient [CO2] increased vegetative mass, digestible dry matter, and concentration of digestible dry matter but decreased leaf:stem and [N]. Increased temperature generally had an effect on forage traits that was opposite to the elevated [CO2] response. The combined effects of both factors sometimes cancelled each other, but usually one of the factors was dominant. Negative effects of temperature tended to be aggravated by dry conditions. At crop maturity, positive effects of elevated atmospheric [CO2] on forage productivity and quality were severely decreased by nutrient and physiological constraints. These simulations indicate that when forage crops are grown under irrigation in semiarid regions, there may be substantial and complex changes in productivity and feed quality as a consequence of warmer temperature and elevated atmospheric [CO2]. Under rainfed conditions, these differences could be quite erratic and virtually unpredictable within the current range of interannual variation in forage productivity and quality.

KEYWORDS: CARBOHYDRATE, CARBON DIOXIDE, CO2-ENRICHMENT, DIGESTIBILITY, DRY-WEIGHT, GROWTH, PLANT, TEMPERATURE, YIELD

2177

Sellers, P.J., F.G. Hall, R.D. Kelly, A. Black, D. Baldocchi, J. Berry, M. Ryan, K.J. Ranson, P.M. Crill, D.P. Lettenmaier, H. Margolis, J. Cihlar, J. Newcomer, D. Fitzjarrald, P.G. Jarvis, S.T. Gower, D. Halliwell, D. Williams, B. Goodison, D.E. Wickland, and F.E. Guertin. 1997. BOREAS in 1997: Experiment overview, scientific results, and future directions. *Journal of Geophysical Research-Atmospheres 102(D24):28731-28769.*

The goal of the Boreal Ecosystem-Atmosphere Study (BOREAS) is to improve our understanding of the interactions between the boreal forest biome and the atmosphere in order to clarify their roles in global change. This overview paper describes the science background and motivations for BOREAS and the experimental design and operations of the BOREAS 1994 and BOREAS 1996 field years. The findings of the 83 papers in this journal special issue are reviewed, In section 7, important scientific results of the project to date are summarized and future research directions are identified.

KEYWORDS: AMAZONIAN FOREST, ATMOSPHERIC CO2, CANOPY, CARBON DIOXIDE, ENERGY, EXCHANGE, FIELD EXPERIMENT FIFE, GENERAL-CIRCULATION MODEL, LAND-SURFACE, WATER-VAPOR

2178

Sellers, P., F. Hall, H. Margolis, B. Kelly, D. Baldocchi, G. Denhartog, J. Cihlar, M.G. Ryan, B. Goodison, P. Crill, K.J. Ranson, D. Lettenmaier, and D.E. Wickland. 1995. The boreal ecosystem-atmosphere study (boreas) - an overview and early results from the 1994 field year. *Bulletin of the American Meteorological Society 76(9):1549-1577.*

The Boreal Ecosystem Atmosphere Study (BOREAS) is a large-scale international field experiment that has the goal of improving our understanding of the exchanges of radiative energy, heat, water, CO2, and trace gases between the boreal forest and the lower atmosphere. An important objective of BOREAS is to collect the data needed to improve computer simulation models of the processes controlling these exchanges so that scientists can anticipate the effects of global change. From August 1993 through September 1994, a continuous set of monitoring measurements-meteorology, hydrology, and satellite remote sensing-were gathered over the 1000 x 1000 km BOREAS study region that covers most of Saskatchewan and Manitoba, Canada. This monitoring program was punctuated by six campaigns that saw the

deployment of some 300 scientists and aircrew into the field, supported by 11 research aircraft. The participants were drawn primarily from U.S. and Canadian agencies and universities, although there were also important contributions from France, the United Kingdom, and Russia. The field campaigns lasted for a total of 123 days and saw the compilation of a comprehensive surface-atmosphere flux dataset supported by ecological, trace gas, hydrological, and remote sensing science observations. The surface-atmosphere fluxes of sensible heat, latent heat, CO2, and momentum were measured using eddy correlation equipment mounted on a surface network of 10 towers complemented by four flux-measurement aircraft. All in all, over 350 airborne missions (remote sensing and eddy correlation) were flown during the 1994 field year. Preliminary analyses of the data indicate that the area-averaged photosynthetic capacity of the boreal forest is much less than that of the temperate forests to the south. This is reflected in very low photosynthetic and carbon drawdown rates, which in turn are associated with low transpiration rates (less than 2 mm day-1 over the growing season for the coniferous species in the area). The strong sensible fluxes generated as a result of this often lead to the development of a deep dry planetary boundary layer over the forest, particularly during the spring and early summer. The effects of frozen soils and the strong physiological control of evapotranspiration in the biome do not seem to be well represented in most operational general circulation models of the atmosphere. Analyses of the data will continue through 1995 and 1996. Some limited revisits to the field are anticipated.

KEYWORDS: CARBON, DYNAMICS, FIFE, MODEL

2179

Seneweera, S.P., A.S. Basra, E.W. Barlow, and J.P. Conroy. 1995. Diurnal regulation of leaf blade elongation in rice by co2 - is it related to sucrose-phosphate synthase activity. *Plant Physiology 108(4):1471-1477.*

The relationship between leaf blade elongation rates (LER) and sucrose-phosphate synthase (SPS) activity was investigated at different times during ontogeny of rice (Oryza safiva L. cv Jarrah) grown in flooded soil at either 350 or 700 mu L CO2 L(- 1). High CO2 concentrations increased LER of expanding blades and in vivo activity (V-limiting) SPS activity of expanded blades during the early vegetative stage (21 d after planting [DAP]), when tiller number was small and growing blades were strong carbohydrate sinks. Despite a constant light environment, there was a distinct diurnal pattern in LER, V- limiting SPS activity, and concentration of soluble sugars, with an increase in the early part of the light period and a decrease later in the light period. The strong correlation (r = 0.65) between LER and V-limiting SPS activity over the diurnal cycle indicated that SPS activity played an important role in controlling blade growth. The higher V-limiting SPS activity at elevated CO, at 21 DAP was caused by an increase in the activation state of the enzyme rather than an increase in V- max. Fructose and glucose accumulated to a greater extent than sucrose at high CO2 and may have been utilized for synthesis of cell-wall components, contributing to higher specific leaf weight. By the mid-tillering stage (42 DAP), CO2 enrichment enhanced V-limiting and V-max activities of source blades. Nevertheless, LER was depressed by high CO2, probably because tillers were stronger carbohydrate sinks than growing blades.

KEYWORDS: CARBON, GROWTH, LEAVES, NITROGEN, PHOTOSYNTHESIS, PLANTS

2180

Seneweera, S., A. Blakeney, P. Milham, A.S. Basra, E.W.R. Barlow, and J. Conroy. 1996. Influence of rising atmospheric CO2 and phosphorus nutrition on the grain yield and quality of rice (Oryza sativa cv. Jarrah). *Cereal Chemistry 73(2):239-243.*

Raising the atmospheric CO2 concentration from 350 mu l of CO2 per liter to a level expected by the end of the next century (700 mu l/L) influenced both the grain yield and quality of the short-duration rice (Oryza sativa) cultivar, Jarrah. Yield was enhanced by up to 58%, primarily due to an increase in grain number, although grain size was also greater at high CO2. Varying the supply of phosphorus influenced the magnitude of the CO2 response with greatest responses occurring at medium rather than luxury or low phosphorus supplies. However, yield enhancement by high CO2 was observed even when phosphorus supply was severely growth limiting. Chemical (amylose and nutrient concentration) and physical (relative paste viscosity) measurements made on the ground grain indicated that cooked rice grain from plants grown under high levels of CO2 would be firmer. The nutritive value of grain was also changed at high CO2 due to a reduction in grain nitrogen and, therefore, protein concentration. However, total nitrogen content per grain was unaffected by high CO2. In contrast, phosphorus content per grain was greater at high CO2 and there was a strong correlation between magnesium and phosphorus concentrations. These results indicate that there is a need to plan for the inevitable rise in atmospheric CO2 concentrations by selecting genotypes that will maintain suitable quality characteristics under global change.

KEYWORDS: CARBON DIOXIDE, GROWTH, STARCH

2181

Seneweera, S.P., and J.P. Conroy. 1997. Growth, grain yield and quality of rice (Oryza sativa L.) in response to elevated CO2 and phosphorus nutrition (Reprinted from Plant nutrition for sustainable food production and environment, 1997). *Soil Science and Plant Nutrition 43:1131-1136.*

The influence of rising atmospheric CO2 concentrations and phosphorus nutrition on growth, grain yield and quality of a early maturing rice cultivar (Oryza sativa L. cv. Jarrah) was investigated by growing plants in a range of phosphorus levels at tither 350 or 700 mu L CO2 L-1 in the growth chambers. Total above ground biomass and grain yield were greater at elevated CO2 concentrations and with increasing phosphorus supply. The CO2 response was evident at all but the lowest phosphorus treatments but its magnitude was greater at moderate phosphorus supplies. The increase in grain yield at high CO2 was due mainly to an enhancement of tiller number. The phosphorus concentration in the foliage was unaffected by CO2 enrichment and the critical concentration of 1.8 g kg(-1) dwt was the same as reported for field-grown rice. The concentration of calcium in the foliage was increased by high CO2 and the nitrogen concentration was reduced, Chemical analysis (amylose and mineral concentration) indicated that cooked rice grain from high-CO2-grown plants would be firmer and that concentrations of Zn and Fe, which are important in the diet of humans, will be lower. These results indicate that there is a need to plan for the inevitable rise in global CO2 concentrations by selecting cultivars which will be more productive and yet maintain suitable quality characteristics under elevated CO2 levels.

KEYWORDS: CARBON DIOXIDE, DURATION, ENRICHMENT, NITROGEN, TEMPERATURE, WHEAT

2182

Seneweera, S.P., O. Ghannoum, and J. Conroy. 1998. High vapour pressure deficit and low soil water availability enhance shoot growth responses of a C-4 grass (Panicum coloratum cv. Bambatsi) to CO2 enrichment. *Australian Journal of Plant Physiology 25(3):287-292.*

The hypothesis that shoot growth responses of C-4 grasses to elevated CO2 are dependent on shoot water relations was tested using a C-4 grass, Panicum coloratum (NAD-ME subtype). Plants were grown for 35 days at CO2 concentrations of 350 or 1000 mu L CO2 L-1. Shoot water relations were altered by growing plants in soil which was brought daily

to 65, 80 or 100% field capacity (FC) and by maintaining the vapour pressure deficit (VPD) at 0.9 or 2.1 kPa. At 350 mu L CO2 L-1, high VPD and lower soil water content depressed shoot dry mass, which declined in parallel at each VPD with decreasing soil water content. The growth depression at high VPD was associated with increased shoot transpiration, whereas at low soil water, leaf water potential was reduced. Elevated CO2 ameliorated the impact of both stresses by decreasing transpiration rates and raising leaf water potential. Consequently, high CO2 approximately doubled shoot mass and leaf length at a VPD of 2.1 kPa and soil water contents of 65 and 80% FC but had no effect on unstressed plants. Water use efficiency was enhanced by elevated CO2 under conditions of stress but this was primarily due to increases in shoot mass. High CO2 had a greater effect on leaf growth parameters than on stem mass. Elevated CO2 increased specific leaf area and leaf area ratio, the latter at high VPD only. We conclude that high CO2 increases shoot growth of C-4 grasses by ameliorating the effects of stress induced by either high VPD or low soil moisture. Since these factors limit growth of field-grown C-4 grasses, it is likely that their biomass will be enhanced by rising atmospheric CO2 concentrations.

KEYWORDS: ELEVATED CO2, HUMIDITY

2183

Seneweera, S., P. Milham, and J. Conroy. 1994. Influence of elevated co2 and phosphorus-nutrition on the growth and yield of a short-duration rice (oryza-sativa L CV jarrah). *Australian Journal of Plant Physiology 21(3):281-292.*

The growth and development of a short-duration rice cultivar (Oryza sativa L. cv. Jarrah), grown in flooded soil with a range of phosphorus (P) levels and exposed to atmospheric CO2 concentrations of either 350 or 700 mu L L(-1) was followed for 146 days after planting (DAP). Development (estimated by rate of tiller production and time to flowering) was faster with higher soil P levels and CO2 enrichment, the effect being more pronounced with CO2 enrichment. During the early vegetative phase (up to 35 DAP), when rates of tiller production were low, shoot growth and rates of leaf expansion were faster at elevated CO2 concentrations and high soil P levels. Rates of tiller production were greater with these treatments during the 35-56 DAP period, when tillering was at a maximum. Shoot elongation was reduced at elevated CO2 levels and at high soil P levels during this period. By 146 DAP leaf weight was greater at high P levels, but CO2 enrichment accelerated tiller production to such an extent that final leaf weight was lower at high CO2, probably because there were fewer, and smaller, leaves on each tiller. Despite this, grain yield was increased by up to 58% by CO2 enrichment, with increases occurring even at low soil P levels. This was due mainly to an increase in grain number per panicle, although panicle number also increased. Higher soil P levels also increased grain number and yield. The P concentration in the foliage was unaffected by the CO2 treatments and the concentration required to produce maximum yield was 0.18% (dry wt basis) at both CO2 levels. Greater starch accumulation in the stems of high-CO2-grown plants may have accounted for the higher number of grains in each panicle.

KEYWORDS: ATMOSPHERIC PARTIAL-PRESSURE, CARBON DIOXIDE, NITROGEN, PLANT GROWTH

2184

Senock, R.S., J.M. Ham, T.M. Loughin, B.A. Kimball, D.J. Hunsaker, P.J. Pinter, G.W. Wall, R.L. Garcia, and R.L. LaMorte. 1996. Sap flow in wheat under free-air CO2 enrichment. *Plant, Cell and Environment 19(2):147-158.*

The effects of elevated carbon dioxide (CO2) concentration on plant water use are best evaluated on plants grown under field conditions and with measurement techniques that do not disturb the natural function of the plant, seat balance sap flow gauges were used on individual main stems of wheat (Triticum aestivun L. cv Yecora rojo) grown under normal ambient conditions (control) and in a free-air CO2 enrichment (FACE) system in Arizona with either high (control+high H2O=CW; FACE+high H2O=FW) or low (control+low H2O=CD; FACE+low H2O=FD) irrigation regimens, Over a 30d period (stem elongation to anthesis), combinations of treatments were monitored with 10-40 gauges per treatment, The effects of increased CO2 on tiller water use were inconsistent in both the diurnal patterns of sap flow and the statistical analyses of daily sap flow (F-tot), Initial results suggested that the reductions in F-tot from CO2 enrichment were small (0-10%) in relation to the H2O treatment effect (20-30%), For a 3d period, F-tot of FW was 19-26% less than that of CW (P=0.10). Examination of the different sources of variation in the study revealed that the location of gauges within the experimental plots influenced the variance of the sap flow measurements, This variation was probably related to positional variation in subsurface drip lines used to irrigate plots, A sampling design was proposed for use of sap flow gauges in FACE systems with subsurface irrigation that takes into account the main treatment effects of CO2 enrichment and the other sources of variation identified in this study, Despite the small and often statistically non-significant differences in F-tot between the CW and FW treatments, cumulative water use of the FW treatment at the end of the first three test periods ranged from 7 to 23% lower than that of the CW treatment, Differences in sap flow between FW and CW compared well with treatment differences in evapotranspiration. The results of the study, based on the first reported sap flow measurements of wheat, suggest that irrigation requirements for wheat production, in the present climatic regimen of the south- western US, may be predicted to decreases lightly because of increasing atmospheric CO2.

KEYWORDS: BALANCE, CARBON DIOXIDE, COTTON, GROWTH, RESPONSES, TRANSPIRATION, WATER-USE

2185

Serraj, R., L.H. Allen, and T.R. Sinclair. 1999. Soybean leaf growth and gas exchange response to drought under carbon dioxide enrichment. *Global Change Biology 5(3):283-291.*

This study was conducted to determine the response in leaf growth and gas exchange of soybean (Glycine man: Merr.) to the combined effects of water deficits and carbon dioxide (CO2) enrichment. Plants grown in pots were allowed to develop initially in a glasshouse under ambient CO2 and well-watered conditions. Four-week old plants were transferred into two different glasshouses with either ambient (360 mu mol mol(-1)) or elevated (700 mu mol mol(-1)) CO2. Following a 2-day acclimation period, the soil of the drought-stressed pots was allowed to dry slowly over a 2-week period. The stressed pots were watered daily so that the soil dried at an equivalent rate under the two CO2 levels. Elevated [CO2] decreased water loss rate and increased leaf area development and photosynthetic rate under both well-watered and drought-stressed conditions. There was, however, no significant effect of [CO2] in the response relative to soil water content of normalized leaf gas exchange and leaf area. The drought response based on soil water content for transpiration, leaf area, and photosynthesis provide an effective method for describing the responses of soybean physiological processes to the available soil water, independent of [CO2].

KEYWORDS: CO2 EXPOSURE, PHOTOSYNTHESIS, PHYSIOLOGY, RICE, SOIL, STAGE, TEMPERATURE, TRANSPIRATION, WATER-STRESS, WHEAT

2186

Serraj, R., T.R. Sinclair, and L.H. Allen. 1998. Soybean nodulation and N-2 fixation response to drought under carbon dioxide enrichment.

Plant, Cell and Environment 21(5):491-500.

The combined effects of carbon dioxide (CO2) enrichment and water deficits on nodulation and N-2 fixation were analysed in soybean [Glycine max (L.) Merr.]. Two shortterm experiments were conducted in greenhouses with plants subjected to soil drying, while exposed to CO2 atmospheres of either 360 or 700 mu mol CO2 mol(-1). Under drought-stressed conditions, elevated [CO2] resulted in a delay in the decrease in Nz fixation rates associated,vith drying of the soil used in these experiments. The elevated [CO2] also allowed the plants under drought to sustain significant increases in nodule number and mass relative to those under ambient [CO2], The total non-structural carbohydrate (TNC) concentration was lower in the shoots of the plants exposed to drought; however, plants under elevated CO2 had much higher TNC levels than those under ambient CO2. For both [CO2] treatments, drought stress induced a substantial accumulation of TNC in the nodules that paralleled N-2 fixation decline, which indicates that nodule activity under drought may not be carbon limited. Under drought stress, ureide concentration increased in all plant tissues. However, exposure to elevated [CO2] resulted in substantially less drought-induced ureide accumulation in leaf and petiole tissues. A strong negative correlation was found between ureide accumulation and TNC levels in the leaves. This relationship, together with the large effect of elevated [CO2] on the decrease of ureide accumulation in the leaves, indicated the importance of ureide breakdown in the response of N-2 fixation to drought and of feedback inhibition by ureides on nodule activity. It is concluded that an important effect of CO2 enrichment on soybean under drought conditions is an enhancement of photoassimilation, an increased partitioning of carbon to nodules and a decrease of leaf ureide levels, which is associated with sustained nodule growth and N-2 rates under soil water deficits. We suggest that future [CO2] increases are likely to benefit soybean production by increasing the drought tolerance of N-2 fixation.

KEYWORDS: AMINO-ACID, GAS-EXCHANGE, GROWTH, NITROGENASE ACTIVITY, OXYGEN PERMEABILITY, REDUCTION ACTIVITY, ROOT NODULE ACTIVITY, STRESS, WATER DEFICIT, WHITE CLOVER

2187

Sgherri, C.L.M., M.F. Quartacci, M. Menconi, A. Raschi, and F. Navari-Izzo. 1998. Interactions between drought and elevated CO2 on alfalfa plants. *Journal of Plant Physiology 152(1):118-124.*

Alfalfa (Medicago sativa L.) plants were grown in open top chambers at ambient (340 ppm) and high (600 ppm) CO2 concentrations. Twenty-five days after the first cutting one set of both plants was subjected to water deficit conditions by withholding water for 5 days. A chamber effect on proteolytic activity, monogalactosyl diacylglycerol to digalactosyl diacylglycerol molar ratio, total non-structural carbohydrates and soluble protein contents occurred. In contrast, no change in leaf water potential was observed between plants grown outdoors and inside the chambers. Plants grown at high CO2 concentration showed a lower decrease in leaf water potential in comparison with plants grown at atmospheric CO2 when subjected to water stress. Under high CO2 concentration leaf nitrogen content decreased whereas starch accumulation and a higher proteolytic activity were recorded. Following water depletion, CO2-enriched plants showed a decrease in total non- structural carbhydrates and soluble proteins. In thylakoid membranes high CO2 caused an increase in chlorophyll and lipid contents and a degradation of monogalactosyl diacylglycerol. A higher degree of unsaturation in the main thylakoid lipids was also observed. CO2-enriched plants were less affected by water stress as shown by reduced chlorophyll degradation and a higher membrane stability.

KEYWORDS: ACIDS, ATMOSPHERIC CARBON-DIOXIDE, FIELD, GROWTH, LIPIDS, PROTEIN, WATER-STRESS

2188

Shafer, S.R., U. Blum, S.J. Horton, and D.L. Hesterberg. 1998. Biomass of tomato seedlings exposed to an allelopathic phenolic acid and enriched atmospheric carbon dioxide. *Water, Air, and Soil Pollution 106(1-2):123-136.*

Increased atmospheric CO2 can affect plant growth, so competition among plants may be influenced. Allelopathy is one mechanism involved in plant competition. Experiments were conducted in a controlled-environment chamber to determine if the concentration of atmospheric CO2 altered the dose-response relationship between an allelopathic phenolic acid and tomato seedling biomass. Seeds of Lycopersicon lycopersicum were planted in quartz sand in styrofoam cups and allowed to germinate and grow for 15-17 days. During the next 14 days, seedlings were watered twice daily with nutrient solution amended with p-coumaric acid (4-hydroxycinnamic acid, HOC6H4CH = CHCO2H; ranging 0-0.85 mg mL(-1); 5 concentrations in each experiment) and exposed 24 hr day(-1) in continuous-stirred tank reactors (CSTRs) to ambient air (335-375 ppm CO2) or ambient air to which 350 ppm CO2 was added (i.e., approximately twice-ambient CO2; two CSTRs per CO2 concentration in each experiment). Dose-response data relating p-coumaric acid concentration and shoot, root, and total biomass were fit to a flexible decay function. In all three experiments, twice- ambient CO2 significantly increased the y-intercept for the dose-response model for the p-coumaric acid effect on shoot biomass by 25-50% but had negligible effects on other aspects of the models. Results suggest that if CO2 affects plant competition, mechanisms involving allelopathic phenolic acids may not be involved.

KEYWORDS: ANNUALS, CO2- ENRICHMENT, CUCUMBER LEAF EXPANSION, ELEVATED CO2, FERULIC ACID, GROWTH, INHIBITION, NUTRIENT CULTURE, PLANT-RESPONSES, RESOURCE USE

2189

Shainsky, L.J., and S.R. Radosevich. 1992. Mechanisms of competition between douglas-fir and red alder seedlings. *Ecology 73(1):30-45.*

Mechanisms of interactions between Douglas-fir (Pseudotsuga menziesii) and red alder (Alnus rubra) seedlings were assessed in experimentally manipulated stands. The density of each species was varied systematically, creating a matrix of competitive regimes that consisted of five monoculture densities and 25 mixtures of all possible pairwise combinations of the monoculture densities. Response surfaces for growth rates, leaf area, photon flux density, soil moisture content and depletion, and plant water potential were generated within the matrix. Regression coefficients quantified the effects of species densities on response variables, and correlation analysis yielded insight into interrelationships between variables. Tree performance, leaf area per square metre of ground surface area, resources, and physiological variables were all quantitatively altered by alder density, Douglas-fir density, and the interaction between species densities. Alder was the dominant competitor and overtopped the Douglas-fir. Competition for light was mediated by density effects on the leaf area of each species per square metre of ground surface area. Increasing alder leaf area reduced the light reaching the understory Douglas-fir. In contrast, increasing Douglas-fir leaf areas increased the light penetrating through to the understory conifers, due to Douglas-fir's suppression of alder leaf area per square metre. Soil moisture limitations were also created by increasing the density of both species and resulted in increasingly negative leaf water potentials for both species. Growth rates concurrently declined as plant water stress increased. Response variables were assembled into a conceptual modeling proposing how species density

regulated growth through the interactions between resource limitations and impairment of physiological function.

KEYWORDS: CANOPY LEAF-AREA, CARBON RELATIONS, CENTRAL EUROPEAN HEDGEROW, ELEVATED CO2, GROWTH, INTERFERENCE, PLANTATIONS, PLANTS, PRODUCTIVITY, WATER RELATIONS

2190
Sharma, A., and U.K. Sengupta. 1997. Carbon allocation and partitioning in Vigna radiata (L.) Wilczek as affected by additional carbon gain. *Photosynthetica 34(3):419-426.*

Carbon allocation to the source leaf export and partitioning to the sink were studied in mungbean supplied by additional carbon from the source leaves subjected to high CO2 concentrations (600 and 900 cm(3) m(-3)) in three metabolic and functional source-sink combinations. The plants were pruned to a source- path-sink system. With CO2 enrichment there was an appreciable increase in net photosynthetic CO2 uptake in earlier formed and physiologically younger leaves. Most of the carbon fixed as a result of enrichment was translocated out of the source leaf within one diurnal cycle. The carbon remaining in the source leaf was unchanged. Partitioning of extra carbon into starch or sugar depended upon the amount of extra carbon synthesized. The unloading of the extra carbon into sinks depended on whether it was used for growth or stored. Under increased carbon content, the leaf as a sink was able to reorganize its metabolic reactions more rapidly to maintain the required gradient for unloading than the pod acting as the sink.

KEYWORDS: CO2 EXCHANGE, DIOXIDE ENRICHMENT, LEAF, LEAVES, METABOLISM, PHOTOSYNTHESIS, RATES, TRANSLOCATION

2191
Sharma-Natu, P., F.A. Khan, and M.C. Ghildiyal. 1997. Photosynthetic acclimation to elevated CO2 in wheat cultivars. *Photosynthetica 34(4):537-543.*

Wheat (T. aestivum) cvs. Kalyansona and Kundan grown under atmospheric (CA) and elevated CO2 concentrations (650-150 cm(3) m(-3) - CE) in open top chambers were examined for net photosynthetic rate (P-N), stomatal limitation (l(S)) of P-N, ribulose-1,5-bisphosphate carboxylase (RuBPC) activity, and saccharide content of the leaves. The P-N values of both CA- and CE-grown plants compared at the same CO2 concentration showed a down regulation under CE at the post-anthesis stage. The negative acclimation of P-N appeared to be due to both stomatal and mesophyll components, and the RuBPC activity got also adjusted. There was a decrease in activation state of RuBPC under CE. In connection with this, an increased accumulation of saccharides in wheat leaf under CE was observed. Kalyansona, owing to its larger sink potential in terms of the number of grains, showed a greater enhancement under CE in both post-ear emergence dry matter production and grain yield. Under CE, this cultivar also showed a lower down regulation of P-N than Kundan.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, CARBOXYLASE ACTIVITY, DIURNAL CHANGES, ENHANCED CO2, EXCHANGE, GROWTH, LEAVES, LONG-TERM, PLANTS

2192
Shaver, G.R., W.D. Billings, F.S. Chapin, A.E. Giblin, K.J. Nadelhoffer, W.C. Oechel, and E.B. Rastetter. 1992. Global change and the carbon balance of arctic ecosystems. *BioScience 42(6):433-441.*

KEYWORDS: ACCUMULATION, ALASKAN TUSSOCK TUNDRA, BOREAL FORESTS, CLIMATE, CO2, DIOXIDE, ERIOPHORUM VAGINATUM, GROWTH, NITROGEN, NUTRIENT

2193
Sheehy, J.E., F. Gastal, P.L. Mitchell, J.L. Durand, G. Lemaire, and F.I. Woodward. 1996. A nitrogen-led model of grass growth. *Annals of Botany 77(2):165-177.*

This model is built by considering the utilization rate of nitrogen as the first step in calculating the rate of growth of the various organs of a grass crop. The amount of carbohydrate determines whether there are sufficient carbon skeletons and sufficient energy available to support synthesis of new material. Growth of roots, tillers/stems and leaves is simulated with leaf divided into photosynthetic and non- photosynthetic structures. The model keeps account of soluble carbohydrate and nitrogen pools in each of the organs and storage pools of carbohydrate in the leaves and roots. The modelled crop has an age structure so that each plant organ has an age profile describing daily changes in growth; when the oldest tissue becomes senescent a fraction of its nitrogen is recycled. Seasonal changes in the percentage nitrogen content of the crop, when large amounts of soil nitrogen are available, are shown to be a consequence of changes in both soluble and stored carbohydrate. The contrast between high and low nitrogen treatments is shown to be a consequence of different allocation priorities for nitrogen. The model demonstrates that considering nitrogen as the primary element of synthesis provides an approach that predicts dry matter production successfully, as well as giving a different perspective of the growth processes, and suggesting that the capacity of the enzymatic processes governing synthesis ultimately limits crop yields. This different perspective may be most useful when trying to understand what controls growth and the relative influence of environmental changes on the physiology and morphology of the crop. (C) 1996 Annals of Botany Company

KEYWORDS: CO2- ENRICHMENT, CROPS, ECOSYSTEMS, ELEVATED CARBON-DIOXIDE, LEAF, LOLIUM-PERENNE, PERENNIAL RYEGRASS, PLANT GROWTH, RESPONSES

2194
Sheppard, M.I., L.L. Ewing, and J.L. Hawkins. 1994. Soil processes and chemical-transport - soil degassing of C-14 dioxide - rates and factors. *Journal of Environmental Quality 23(3):461-468.*

Soil air normally contains elevated levels of CO2 relative to the atmosphere. The primary source of soil C is plant-root and microbial respiration. The exchange of soil and atmospheric CO2 is important to many environmental concerns, such as acid rain, global warming and waste management. Proposed disposal of high- level nuclear wastes containing primarily inorganic C-14 may provide a source of (CO2)-C-14 to the atmosphere. Field and laboratory experiments show that (CO2)-C-14 Soil degassing rate constants, the flux density (Bq.M2.s-1) divided by soil inventory (Bq-m-2), range from -10(-7) to -10(-2) S-1, and that the loss of inorganic C-14 is driven primarily by gaseous diffusion. These constants are affected by soil pH and porosity, with smaller influences of soil temperature, moisture and organic matter content. Degassing rate constants derived through mass balance calculations to estimate loss differ only by 20% from direct trapping methods. Frozen soil degassing rate constants were up to 25 times smaller than lab values, indicating that annual C-14 loss rates in northern climates would be lower because of reduced gaseous diffusion during the winter months. Using our field data, we recommend an annual C- 14 soil degassing rate constant of -1 x 10(-6) s-1 for acidic soils and a value of -5 x 10(-7) S-1 for calcareous soils. For probabilistic assessment modelling, we recommend a geometric mean degassing constant of -4.3 X 10(-7) S-1 with a geometric standard deviation of 3.26 for three different soils. This indicates the median half-life of C-14

in surface soils is 18 d, with a 99% confidence interval of 13 h and 640 d.

KEYWORDS: CO2, GAS-TRANSPORT, LAW, MODEL, NUCLEAR-FUEL WASTE, UNSATURATED ZONE, VADOSE ZONE

2195
Sheu, B.H., and C.K. Lin. 1999. Photosynthetic response of seedlings of the sub-tropical tree Schima superba with exposure to elevated carbon dioxide and temperature. *Environmental and Experimental Botany 41(1):57-65.*

Seedlings of Schima superba were exposed to both ambient (375 ppm) and 720 ppm levels of CO2 in combination with two incubation temperatures (25/20, 30/25 degrees C, day/night) for a six-month period. Net height growth of seedlings was enhanced in the early period of exposure to high levels of CO2. However, when seedlings were exposed for a longer period of time to this high concentration, net height growth was inhibited. Decreased photosynthetic rate with elevated CO2 was observed when measured in the ambient CO2 over a long-term exposure of 6 months. In contrast, a significant increase in photosynthesis was noted for seedlings exposed to higher incubation temperature in either ambient or 720 ppm CO2 concentrations. The response of CO2 assimilation to internal Ci was indicated by the lower sensitivity in seedlings grown in elevated CO2 concentration. Though this response could also be found in a higher sensitivity in seedlings grown at higher temperature, the seedlings grown in normal conditions (ambient CO2 and temperature) were still more sensitive to CO2 assimilation response to internal Ci. This experiment suggests that: (1) exposure of seedlings to higher CO2 levels for longer periods may lead to a decrease in seedling height growth and photosynthetic rate, as well as decreasing sensitivity to changing internal CO2 concentrations; (2) the optimum temperature for photosynthesis of seedlings grown in an elevated CO2 concentration was higher than that for seedlings grown in ambient concentration.

KEYWORDS: ACCLIMATION, ALLOCATION, CARBOXYLASE, GROWTH, HIGH ATMOSPHERIC CO2, PERSPECTIVE, PLANTS, PRODUCTIVITY, SOURCE-SINK RELATIONS

2196
Shipley, B., M. Lechowicz, S. Dumont, and W.H. Hendershot. 1992. Interacting effects of nutrients, ph-al and elevated co2 on the growth of red spruce (picea-rubens sarg) seedlings. *Water, Air, and Soil Pollution 64(3-4):585-600.*

A 4 mo growth chamber experiment was conducted to evaluate the presence and importance of interactions between nutrient supply, atmospheric CO2 concentration, and four different combinations of pH - Al concentration on the growth, vitality, and tissue element concentrations of 1-yr-old red spruce seedlings. Solution chemistry was chosen to simulate soil conditions at a red spruce dic-back site at Roundtop Mountain (Quebec) that has high acid loadings. CO2 levels were chosen to simulate ambient levels and those expected in the next century. All three experimental factors affected growth and all factors except CO2 affected the visual symptoms of die-back. There was an important interaction between nutrient levels and the different pH - Al combinations, indicating that the response of red spruce to various pH and Al concentrations changes with soil fertility. The positive growth response to enriched CO2 was not sufficient to offset the negative effects of the acid rain induced stresses. A principal component analysis showed that multivariate functions of foliar element concentrations could clearly distinguish plants from different experimental regimes.

KEYWORDS: ACID-RAIN, ALUMINUM, CARBON DIOXIDE, CLIMATE, FORESTS, INCREASING CO2, LOBLOLLY-PINE, OZONE, RESPONSES, TREE SEEDLINGS

2197
Shugart, H.H., T.M. Smith, and W.M. Post. 1992. The potential for application of individual-based simulation- models for assessing the effects of global change. *Annual Review of Ecology and Systematics 23:15-38.*

KEYWORDS: BOREAL FORESTS, CO2-INDUCED CLIMATE CHANGE, COMPUTER-MODEL, ENVIRONMENTAL-FACTORS, EVALUATING PERFORMANCE, FOREST SUCCESSION MODELS, INTERIOR ALASKA, PLANT- COMMUNITIES, STAND DEVELOPMENT, VEGETATION DYNAMICS

2198
Sicher, R. 1995. Diurnal amylolytic activity in soybean leaves grown at ambient and elevated co2. *Plant Physiology 108(2):55.*

2199
Sicher, R.C. 1997. Irradiance and spectral quality affect chlorosis of barley primary leaves during growth in elevated carbon dioxide. *International Journal of Plant Science 158(5):602-607.*

The development of chlorosis was studied in primary leaves of barley plants (Hordeum vulgare L. cv. Brant) grown at ambient and twice-ambient CO, partial pressures. Leaf yellowing was observed 17 d after sowing when plants were grown in controlled environment chambers equipped with high-intensify discharge lamps at an irradiance of 800 mu mol quanta m(-2) s(-1). The extent of leaf yellowing, measured as changes of total chlorophyll, increased when the CO, partial pressure was raised from 37 to 70 Pa. Chlorosis was increased further by increasing the irradiance from 800 to 1100 mu mol quanta m(-2) s(-1). Rates of photosynthetic O-2 evolution by primary leaves,measured 17 d after sowing, were 20% lower for elevated compared with ambient CO2-grown plants. This result agreed with the level of chlorosis. However soluble protein, Rubisco protein (ribulose, 1,5-bisphosphate carboxylase/oxygenase), and initial and total Rubisco activity 17 d after sowing were unaffected by CO2 enrichment and the extent of chlorosis. Leaf starch, sucrose, and glucose were increased by elevated CO2 treatment at almost every sampling. However,only glucose was correlated with leaf damage. Leaf yellowing also was observed on primary leaves of plants grown under microwave-powered sulfur lamps at 800 but not at 550 mu mol quanta m(-2) s(-1). The extent of leaf yellowing on plants grown under microwave- powered sulfur lamps was unaffected by CO2 enrichment. It was concluded that leaf yellowing was influenced by irradiance, photoquality, and CO2 enrichment. Photobleaching of antenna chlorophyll, rather than premature senescence, was the most Likely cause of visible leaf injury in barley.

KEYWORDS: ACCUMULATION, CARBOHYDRATE, CHLOROPHYLL CONTENT, CO2 CONCENTRATION, ENRICHMENT, FOLIAR DEFORMATION, FRUIT PRODUCTION, HIGH-PRESSURE SODIUM, PLANTS, TOMATO GENOTYPES

2200
Sicher, R.C. 1998. Yellowing and photosynthetic decline of barley primary leaves in response to atmospheric CO2 enrichment. *Physiologia Plantarum 103(2):193-200.*

The photosynthetic response of barley (Hordeum vulgare L. cv. Brant) primary leaves was studied as a function of chlorosis induced by CO2 enrichment. Leaf yellowing; measured as changes of chlorophyll a and b, was more extensive in controlled environments at elevated (680 +/- 17

mu l l(-1)) than at ambient (380 +/- 21 mu l l(-1)) CO2. Stomatal conductance of primary leaves was decreased by growth in elevated CO2 between 11 and 18 days after sowing (DAS) when measured at both 380 and 680 mu l l(-1) CO2. Internal leaf CO2 concentration (C-i) was also lower for elevated- compared to ambient-CO2-grown primary leaves between 11 and 14 DAS. Results suggest that non-stomatal factors were responsible for the decreased photosynthetic rates of elevated- compared to ambient-CO2-grown primary leaves 18 DAS. Various photochemical measurements, including quantum absorptance (alpha), minimal (F-0), maximal (F-m), and variable (F-v) chlorophyll fluorescence, as well as the F-v/F-m ratio, were significantly decreased 18 DAS in the elevated- compared to ambient-CO2 treatment. Photochemical (q(P)) and nonphotochemical (q(N)) chlorophyll fluorescence quenching: coefficients of 18-day-old primary leaves did not differ between CO2 treatments. Photosynthetic electron transport rates of photosystem II were slightly lower for elevated- compared to ambient-CO2-grown primary leaves 18 DAS. Concentrations of alpha-amino N (i.e. free amino acids) in barley primary leaves were increased by CO2 enrichment 10 DAS, but subsequently, alpha-amino N decreased in association with photosynthetic decline. Total acid protease activity was greater in elevated- than in ambient-CO2-grown leaves 18 DAS. The above findings suggest that photoinhibition and premature senescence were factors in the CO2-dependent yellowing of barley primary leaves.

KEYWORDS: CARBON-DIOXIDE ENRICHMENT, CHLOROPHYLL FLUORESCENCE, FOLIAR DEFORMATION, FRUIT PRODUCTION, GROWTH, LEAF, LONG-TERM EXPOSURE, TOMATO, WHEAT, YIELD

2201

Sicher, R.C. 1999. Photosystem-II activity is decreased by yellowing of barley primary leaves during growth in elevated carbon dioxide. *International Journal of Plant Science 160(5):849-854.*

Leaf yellowing was studied in 10-18-d-old barley seedlings (Houdeum vulgare L. cv. Brant) grown at ambient (38 Pa) and at elevated (68, 100, and 140 Pa) CO2 partial pressures in controlled-environment chambers. Maximal total chlorophyll (Chl) concentrations of primary leaves from all four CO2 growth treatments were 0.36 +/- 0.01 g m(-2), and these concentrations were observed 10-12 d after sowing (DAS). Total Chi levels in primary leaves were 35%, 64%, and 78% below maximal levels in the 38, 68, and 100 Pa CO2 growth treatments, respectively, when measured 18 DAS. Losses of Chi in 18-d-old primary leaves were similar in the 100 and 140 Pa CO2 treatments. Decreases of Chi d and Chi b in response to CO2 enrichment were comparable in isolated chloroplast preparations and in intact 18-d-old barley primary leaves of plants grown at 38 and 68 Pa CO2. Total thylakoid membrane proteins, the Chi alb binding protein (LHC-II), and D1 protein levels were also lower in chloroplast preparations from plants grown in the elevated compared to the ambient CO2 treatment. Both ferricyanide reduction and whole- chain electron-transport rates (H2O --> methylviologen) were significantly lower for chloroplasts from plants grown at 68 Pa CO2 compared with those grown at 38 Pa CO2. However, photosystem-I-dependent chloroplast photoreductions did not differ between CO2 treatments. The results indicated that the CO2-dependent yellowing of barley primary leaves adversely affected photosystem-II activity. Growth in elevated CO2 may have increased the susceptibility of photosystem-II to light damage.

KEYWORDS: ATMOSPHERIC CO2 ENRICHMENT, CHLOROPHYLL, CHLOROSIS, EXCHANGE, FOLIAR DEFORMATION, IRRADIANCE, PHOTOSYNTHESIS, PLANTS, PROTEINS, TOMATO

2202

Sicher, R.C., and J.A. Bunce. 1997. Relationship of photosynthetic acclimation to changes of Rubisco activity in field-grown winter wheat and barley during growth in elevated carbon dioxide. *Photosynthesis Research 52(1):27-38.*

The responses of photosynthesis, Rubisco activity, Rubisco protein, leaf carbohydrates and total soluble protein to three carbon dioxide treatments were studied in winter wheat [Triticum aestivum (L.)] and barley [Hordeum vulgare (L.)]. Barley and wheat plants were grown in small field plots during 1995 and 1996 in clear, acrylic chambers (1.2-2.4 m(2)) and were provided with continuous carbon dioxide fertilization at concentrations of 350, 525 and 700 mu mol mol(-1). Photosynthetic rates of barley penultimate leaves and wheat flag leaves measured at growth carbon dioxide concentrations decreased with leaf age in all three CO2 treatments during 1995 and 1996. Photosynthetic acclimation to elevated CO2 was observed on seven of eight measurement dates for barley and ten of eleven measurement dates for wheat over both years. Initial Rubisco activity, total soluble protein and Rubisco protein in barley penultimate leaves and wheat flag leaves also decreased with leaf age. Total Rubisco activity was not used because of enzyme degradation. There was a significant CO2 treatment effect on initial Rubisco activity, total soluble protein and Rubisco protein for wheat in 1995 and 1996 and for barley in 1995. Responses of barley penultimate leaf Rubisco activity and leaf protein concentrations to elevated carbon dioxide were nonsignificant in 1996. A significant CO2 treatment effect also was detected when means of Rubisco activity, soluble protein and Rubisco protein for wheat flag leaves were combined over harvests and years. These three flag leaf parameters were not significantly different in the 350 and 525 mu mol mol(-1) CO2 treatments but were decreased during growth in 700 mu mol mol(- 1) CO2 relative to the other two CO2 treatments. Ratios of photosynthesis at 700 and 350 mu mol mol(-1) were compared to ratios of Rubisco activity at 700 and 350 mu mol mol(-1) using wheat flag leaf data from 1995 and 1996. Regression analysis of these data were linear [y = 0.586 + 1.103x(r(2) = 0.432)] and were significant at P less than or equal to 0.05. This result indicated that photosynthetic acclimation was positively correlated with changes of initial Rubisco activity in wheat flag leaves in response to CO2 enrichment. Effects of elevated CO2 on wheat leaf proteins during 1995 and 1996 and on barley during 1995 were consistent with an acceleration of senescence.

KEYWORDS: ATMOSPHERIC CO2, ENRICHMENT, PLANTS, PROTEINS, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, YIELD

2203

Sicher, R.C., and J.A. Bunce. 1998. Evidence that premature senescence affects photosynthetic decline of wheat flag leaves during growth in elevated carbon dioxide. *International Journal of Plant Science 159(5):798-804.*

Net CO2 exchange (NCE) rates and various flag leaf constituents were measured in wheat plants (Triticum aestivum L.) grown in field chambers at either 350 or 700 mu L L-1 CO2. Rates of NCE decreased with leaf age in both CO2 treatments during 1997. A stimulation of NCE initially occurred in response to CO2 enrichment, but this was not observed on the final eight of 33 experimental days. Net photosynthetic rates in response to growth at elevated CO2 were decreased ca. 22% on average for all measurement dates in 1997 and when all NCE rates measured at elevated CO2 for 1995-1997 were averaged (P less than or equal to 0.0001). Soluble protein, alpha-amino nitrogen, and Chi a + b concentrations were significantly lower (P less than or equal to 0.0001) in elevated compared with ambient CO2-grown wheat flag leaves in 1997. The treatment by date interactions for these Rag leaf constituents were nonsignificant (P greater than or equal to 0.05). Flag leaf storage carbohydrates were measured on 10 dates in 1997, but only starch and sucrose were affected by the elevated CO2 treatment. An increase of acid proteinase activity was observed on the last two measurement dates of this study. However, changes of acid proteinase activity were unaffected

by CO2 enrichment (P greater than or equal to 0.05) and only occurred during late stages of senescence. These findings supported the suggestion that premature senescence contributed to the photosynthetic decline observed in wheat flag leaves during growth at elevated CO2. Changes of alpha-amino nitrogen were correlated with photosynthetic decline, but acid proteinase activity probably was under endogenous control.

KEYWORDS: ACCLIMATION, ACCUMULATION, CARBOXYLASE, ENRICHMENT, GRAIN-GROWTH, INCREASING ATMOSPHERIC CO2, LEAF, NITROGEN REDISTRIBUTION, PROTEINS, TRITICUM-AESTIVUM L

2204

Sicher, R.C., and D.F. Kremer. 1994. Responses of nicotiana-tabacum to co2 enrichment at low-photon flux-density. *Physiologia Plantarum 92(3):383-388.*

Effects of CO2 enrichment on photosynthesis and on dry matter allocation were examined in two tobacco (Nicotiana tabacum L.) genotypes, Samsun and W38. Plants were grown from seed in controlled environment chambers at a photosynthetic photon flux density of 450 mu mol m(-2) s(-1). Averaged over the 9 day study, net photosynthesis rates were 14.2 +/- 0.5 and 13.0 +/- 0.4 mu mol m(-2) s(-1) in elevated (70 Pa) and in ambient (35 Pa) CO2 air, respectively, when measured at the irradiance and CO2 partial pressure employed for plant growth. However, photosynthesis rates of plants grown in elevated CO2 were 50% less than those of the ambient controls on the last day of treatment, when measured at 70 Pa CO2 air and an irradiance of 900 mu mol m(-2) s(-1). Total plant dry weight and specific leaf weight were greater (P<0.05) in enriched-CO2-grown than in ambient-CO2-grown plants. Leaf starch, measured during the first hour of the photoperiod, increased over 7 days of treatment in elevated-CO2-grown but not in ambient-CO2-grown plants. Ribulose 1,5-bisphosphate carboxylase/oxygenase (Rubisco) activities of tobacco plants grown at 35 and 70 Pa CO2 air were 58.5 +/- 4.5 and 48.5 +/- 3.7 mu mol m(-2) s(-1), respectively, between days 0 and 9 of the study. Rubisco activation stale, Rubisco protein concentration, soluble protein and total chlorophyll were unaffected by CO2 enrichment. The above findings demonstrated that photosynthesis was down regulated in tobacco plants after 7 to 9 days of CO2 enrichment at low photosynthetic photon flux density, but less than at moderate irradiances.

KEYWORDS: ACCLIMATION, ANTISENSE RBCS, CARBON-DIOXIDE CONCENTRATION, ELEVATED CO2, GROWTH, HIGH ATMOSPHERIC CO2, LEAVES, PHOTOSYNTHESIS, RIBULOSE BISPHOSPHATE CARBOXYLASE, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE

2205

Sicher, R.C., and D.F. Kremer. 1996. Rubisco activity is altered in a starchless mutant of Nicotiana sylvestris grown in elevated carbon dioxide. *Environmental and Experimental Botany 36(4):385-391.*

Dry matter and net photosynthesis of a wild type and a starchless mutant NS 458 of Nicotiana sylvestris (Speg. et Comes) were studied after 25 d of CO2 enrichment. Plants were grown from seed in controlled environment chambers and treatments of either ambient (35 Pa) or twice ambient (70 Pa) CO2 were initiated when plants were 3-4 weeks old. Photosynthetic rates measured at 35 and 70 Pa CO2 and at 900 mu mole quanta m(-2) s(-1) were unaffected (P>0.05) by 25 d of CO2 enrichment. However, a CO2-by-genotype interaction was observed indicating that photosynthetic rates of the wild type but not the mutant at 35 Pa CO2 differed in response to CO2 enrichment. Photosynthetic enhancement was greater (P < 0.001) in the wild type than in the mutant when the measurement CO2 was doubled. Total biomass and leaf areas of the mutant and wild type also were unaffected by CO2 enrichment, although specific leaf weight increased 27% and 13% (P<0.001) for the wild type and mutant lines, respectively. Neither chlorophyll nor soluble leaf protein were affected by CO, enrichment. Starch, sucrose, glucose and fructose in wild type and mutant leaf samples were also unaffected by CO2 enrichment. Rubisco protein levels of the wild type and mutant were about 20% lower in elevated compared to ambient CO2-grown plants. Initial and total Rubisco activities of wild type and mutant leaf samples were not significantly different (P>0.05) between CO2 environments. However, initial Rubisco activity was more than 30% lower in mutant than than in wild type samples when results from ambient and elevated CO2-grown plants were combined. Ribulose 1,5-bisphosphate and 3-phosphoglycerate were 280% and 28% greater in the mutant than in the wild type, respectively. These findings suggested that photosynthesis rates of the mutant were limited by Rubisco activity at 35 Pa CO2 and that end product synthesis rates limited photosynthesis of the mutant at 70 Pa CO2.

KEYWORDS: ACCLIMATION, ATMOSPHERIC CO2, C-3 PLANTS, CARBOXYLASE, ENZYME, LEAVES, PHOSPHOGLUCOMUTASE, PHOTOSYNTHESIS, STEADY-STATE

2206

Sicher, R.C., D.F. Kremer, and J.A. Bunce. 1995. Photosynthetic acclimation and photosynthate partitioning in soybean leaves in response to carbon dioxide enrichment. *Photosynthesis Research 46(3):409-417.*

Photosynthetic rates and photosynthate partitioning were studied in three-week-old soybean [Glycine max (L.) Merr. cv. Williams] plants exposed to either ambient (35 Pa) or elevated (70 Pa) CO2 in controlled environment chambers. Ambient CO2- grown plants also were given a single 24 h treatment with 70 Pa CO2 1 d prior to sampling. Photosynthetic rates of ambient CO2- grown plants initially increased 36% when the measurement CO2 was doubled from 35 to 70 Pa. Photosynthetic rates of the third trifoliolate leaf, both after 1 and 21 d of elevated CO2 treatment, were 30 to 45% below those of ambient CO2-grown plants when measured at 35 Pa CO2. These reduced photosynthetic rates were not due to increased stomatal resistance and were observed for 2 to 8 h after plants given 1 d of CO2 enrichment were returned to ambient CO2. Initial and total ribulose 1,5- bisphosphate carboxylase/oxygenase (Rubisco) activities, percent activation, Rubisco protein, soluble protein and leaf chlorophyll content were similar in all CO2 treatments. Quantum yields of photosynthesis, determined at limiting irradiances and at 35 Pa CO2, were 0.049 +/- 0.003 and 0.038 +/- 0.005 mol CO2 fixed per mol quanta for ambient and elevated CO2-grown plants, respectively (p < 0.05). Leaf starch and sucrose levels were greater in plants grown at 70 than at 35 Pa CO2. Starch accumulation rates during the day were greater in ambient CO2- grown plants than in plants exposed to elevated CO2 for either 1 or 21 d. However, the percentage of C partitioned to starch relative to total C fixed was unaffected by 1 d of CO2 enrichment. The above results showed that both photosynthetic and starch accumulation rates of soybean leaflets measured at 35 Pa CO2 were temporarily reduced after 1 and 21 d of CO2 enrichment. The biochemical mechanism affecting these responses was not identified.

KEYWORDS: CARBOHYDRATE, ELEVATED ATMOSPHERIC CO2, EXPOSURE, GROWTH, LIGHT, RIBULOSE BISPHOSPHATE CARBOXYLASE, SEEDLINGS, STARCH, SUCROSE SYNTHESIS, TEMPERATURE

2207

Sicher, R.C., D.F. Kremer, and S.R. Rodermel. 1993. Role of rubisco during acclimation of transformed tobacco to co2 enriched atmospheres. *Plant Physiology 102(1):88.*

2208

Sicher, R.C., D.F. Kremer, and S.R. Rodermel. 1994. Photosynthetic acclimation to elevated co2 occurs in transformed tobacco with decreased ribulose-1,5-bisphosphate carboxylase/oxygenase content. *Plant Physiology 104(2):409-415.*

Inhibition of net carbon assimilation rates during growth at elevated CO2 was studied in transgenic tobacco (Nicotiana tabacum L.) plants containing zero to two copies of antisense DNA sequences to the small subunit polypeptide (rbcS) gene of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco). High- and low-Rubisco tobacco plants were obtained from the selfed progeny of the original line 3 transformant (S.R. Rodermel, M.S. Abbott, L. Bogorad [1988] Cell 55: 673-681). Assimilation rates of high- and low-Rubisco tobacco plants increased 22 and 71%, respectively, when transferred from 35- to 70-Pa CO2 chamber air at 900 mu mol m(-2) s(-1) photon flux density. However, CO2-dependent increases of net carbon assimilation rates of high- and low-Rubisco plants virtually disappeared after 9 d of growth in elevated CO2 chamber air. Total above-ground dry matter production of high- and low- Rubisco plants was 28 and 53% greater, respectively, after 9 d of growth at 70 Pa compared with 35 Pa CO2. Most of this dry weight gain was due to increased specific leaf weight. Rubisco activity, Rubisco protein, and total chlorophyll were lower in both high- and low-Rubisco plants grown in enriched compared with ambient CO2 chamber air. Soluble leaf protein also decreased in response to CO2 enrichment in high- but not in low-Rubisco tobacco plants. Decreased Rubisco activities in CO2-adapted high- and low-Rubisco plants were not attributable to changes in activation state of the enzyme. Carbonic anhydrase activities and subunit levers measured with specific antibodies were similar in high- and low-Rubisco tobacco plants and were unchanged by CO2 enrichment. Collectively, these findings suggested that photosynthetic acclimation to enriched CO2 occurred in tobacco plants either with or without transgenically decreased Rubisco levels and also indicated that the down-regulation of Rubisco in CO2-adapted tobacco plants was related to decreased specific activity of this enzyme.

KEYWORDS: ANHYDRASE, ANTISENSE RBCS, CARBON DIOXIDE, GROWTH, HIGH ATMOSPHERIC CO2, LIGHT, OXYGENASE, PLANTS, PROTEIN, RIBULOSE BISPHOSPHATE CARBOXYLASE

2209

Siebke, K., and E. Weis. 1995. Imaging of chlorophyll-a-fluorescence in leaves: Topography of photosynthetic oscillations in leaves of Glechoma hederacea. *Photosynthesis Research 45(3):225-237.*

Images of chlorophyll-alpha-fluorescence oscillations were recorded using a camera-based fluorescence imaging system. Oscillations with frequencies around 1 per min were initiated by a transient decrease in light intensity during assimilation at an elevated CO2-concentration. The oscillation was inhomogenously distributed over the leaf. In cells adjacent to minor veins, frequency and damping rate was high, if there was any oscillation. In contrast, the amplitude was highest in cells most distant from phloem elements (maximal distance about 300 mu m). The appearance of minor veins in oscillation images is explained by a gradient in the metabolic control in the mesophyll between minor veins and by transport of sugar from distant cells to phloem elements. The potential of fluorescence imaging to visualize 'microscopic' source-sink interactions and metabolic domains in the mesophyll is discussed.

KEYWORDS: CALVIN-CYCLE, CARBON METABOLISM, CO2 FIXATION, ELECTRON-TRANSPORT, FRUCTOSE 2;6-BISPHOSPHATE, INVIVO, LIMITATION, PHOSPHORYLATION, SPINACH LEAF-DISKS, SUCROSE PHOSPHATE SYNTHASE

2210

Signora, L., N. Galtier, L. Skot, H. Lucas, and C.H. Foyer. 1998. Over-expression of sucrose phosphate synthase in Arabidopsis thaliana results in increased foliar sucrose/starch ratios and favours decreased foliar carbohydrate accumulation in plants after prolonged growth with CO2 enrichment. *Journal of Experimental Botany 49(321):669-680.*

Arabidopsis thaliana ecotype Columbia was transformed with a maize sucrose phosphate synthase (SPS) cDNA under the control of the promoter for the small subunit of ribulose-l,5- bisphosphate carboxylase from tobacco (rbcS). The effects of SPS over-expression were compared in plants of the T-2 and T-3 generations grown either in air or with CO2 enrichment (700 mu l l(-1)) for either 4 or 10 weeks. Maximal extractable foliar SPS activities were three times those of the untransformed controls in the highest rbcS-SPS expressing line. In untransformed Arabidopsis leaves SPS activity was not subject to light/dark regulation, but was modified by incubation with either the inhibitor, orthophosphate, or the activator, mannose. Photosynthesis (A(max)) values were similar in all lines grown in air. After 10 weeks of CO, enrichment a decrease in A,,, in the untransformed controls, but not in the high SPS expressors, was observed. There was a strong correlation between the sucrose-to-starch ratio of the leaves and their SPS activity in both growth conditions. The total foliar carbohydrate contents of 4-week-old plants was similar in all lines whether plants were grown in air or with CO2 enrichment, After 10 weeks growth the leaves of the high rbcS-SPS expressors accumulated much less total carbohydrate than untransformed control leaves in both growth conditions. It was concluded that SPS overexpression causes increased foliar sucrose/starch ratios in Arabidopsis leaves and favours decreased foliar carbohydrate contents when plants are grown for long periods with CO2 enrichment.

KEYWORDS: ATMOSPHERIC CO2, ELECTRON-TRANSPORT, ENZYME-ACTIVITIES, INORGANIC- PHOSPHATE, KINETIC-PROPERTIES, LIGHT-MODULATION, SINK REGULATION, SPINACH LEAVES, TRANSCRIPT LEVELS, TRANSGENIC PLANTS

2211

Sild, E., S. Younis, H. Pleijel, and G. Sellden. 1999. Effect of CO2 enrichment on non-structural carbohydrates in leaves, stems and ears of spring wheat. *Physiologia Plantarum 107(1):60-67.*

Field-grown spring wheat (Triticum aestivum L, cv, Dragon) was exposed to ambient and elevated CO2 concentrations (15 and 2 times ambient) in open-top chambers. Contents of non-structural carbohydrates mere analysed enzymatically in leaves, stems and ears six times during the growing season. The impact of elevated CO2 on wheat carbohydrates was non-significant in most harvests. However, differences in the carbohydrate contents due to elevated CO2 were found in all plant compartments. Before anthesis, at growth stage (GS) 30 (the stem is 1 cm to the shoot apex), the plants grown in elevated CO2 contained significantly more mater soluble carbohydrates (WSC), fructans, starch and total non-structural carbohydrates (TNC) in the leaves in comparison with the plants groan in ambient CO2. It is hypothesised that the plants from the treatments with elevated CO2 were sink-limited at GS30, After anthesis, the leaf WSC and TNC contents of the plants from elevated CO2 started to decline earlier than those of the plants from ambient CO2. This may indicate that the leaves of plants grown in the chambers with elevated CO2 senesced earlier. Elevated CO2 accelerated grain development: 2 weeks after anthesis, the plants groan in elevated CO2 contained significantly more starch and significantly less fructans in the ears compared to the plants grown in ambient CO2. Elevated CO2 had no effect on ear starch and TNC contents at the final harvest. Increasing the CO2 concentration from 360 to 520 mu mol mol(-1) had a larger effect on wheat nonstructural carbohydrates than the further increase from 520 to 680 mu mol mol(-1). The results are discussed in relation to the effects of elevated CO2 on yield and yield components.

KEYWORDS: ATMOSPHERIC CO2, ELEVATED CO2, FRUCTAN ACCUMULATION, GRAIN-YIELD, GROWTH, LONG-TERM, PHOTOSYNTHESIS, RESPONSES, TRITICUM-AESTIVUM L, WINTER-WHEAT

2212
Silver, W.L. 1998. The potential effects of elevated CO2 and climate change on tropical forest soils and biogeochemical cycling. *Climatic Change 39(2-3):337-361.*

Tropical forests are responsible for a large proportion of the global terrestrial C flux annually for natural ecosystems. Increased atmospheric CO2 and changes in climate are likely to affect the distribution of C pools in the tropics and the rate of cycling through vegetation and soils. In this paper, I review the literature on the pools and fluxes of carbon in tropical forests, and the relationship of these to nutrient cycling and climate. Tropical moist and humid forests have the highest rates of annual net primary productivity and the greatest carbon flux from soil respiration globally. Tropical dry forests have lower rates of carbon circulation, but may have greater soil organic carbon storage, especially at depths below 1 meter. Data from tropical elevation gradients were used to examine the sensitivity of biogeochemical cycling to incremental changes in temperature and rainfall. These data show significant positive correlations of litterfall N concentrations with temperature and decomposition rates. Increased atmospheric CO2 and changes in climate are expected to alter carbon and nutrient allocation patterns and storage in tropical forest. Modeling and experimental studies suggest that even a small increase in temperature and CO2 concentrations results in more rapid decomposition rates, and a large initial CO2 efflux from moist tropical soils. Soil P limitation or reductions in C:N and C:P ratios of litterfall could eventually limit the size of this flux. Increased frequency of fires in dry forest and hurricanes in moist and humid forests are expected to reduce the ecosystem carbon storage capacity over longer time periods.

KEYWORDS: AMAZONIAN RAINFOREST, GLOBAL CARBON-CYCLE, LITTER DECOMPOSITION, LOA ENVIRONMENTAL MATRIX, LUQUILLO EXPERIMENTAL FOREST, MULU NATIONAL PARK, NUTRIENT AVAILABILITY, ORGANIC-MATTER, PUERTO-RICO, TERRESTRIAL ECOSYSTEMS

2213
Silvola, J., and U. Ahlholm. 1993. Effects of co2 concentration and nutrient status on growth, growth rhythm and biomass partitioning in a willow, salix- phylicifolia. *Oikos 67(2):227-234.*

Cuttings of the willow Salix phylicifolia were grown in pots containing moist organic-rich soil for four months in closed chambers at 4 CO2 concentrations (300). 500, 700, 1000 ppm) and 4 nutrient levels (fertilization of 0, 100, 500, 1000 kg ha-1 monthly). The plants received natural light, but the average temperature was 3-6-degrees-C higher than out of doors. Both CO2 concentration and fertilization affected biomass production. the average increase caused by CO2 enhancement being approx. 100%. Nutrient level had a considerable effect on the increased biomass production achieved by CO2 enhancement, since the increase was minimal at lower nutrient levels. At the same time the effect of fertilization was dependent on the CO2 concentration, the production increase caused by fertilization being much less at 300 ppm than at the other CO2 concentrations. CO2 concentration and fertilization had the opposite effects on biomass partitioning, a higher nutrient level increasing the proportion of the biomass located in the stems and a higher CO2 concentration that in the roots. Both fertilization and CO2 concentration affected the growth rhythm, a high CO2/nutrient ratio leading to a shorter growing season and a low ratio to a longer one.

KEYWORDS: ATMOSPHERIC CARBON-DIOXIDE, DRY-MATTER PRODUCTION, ELEVATED CO2, ENRICHMENT, INCREASE, NITROGEN, PHOTOSYNTHETIC RATE, SEEDLINGS, SENESCENCE, TREES

2214
Silvola, J., and U. Ahlholm. 1995. Combined effects of co2 concentration and nutrient status on the biomass production and nutrient-uptake of birch seedlings (betula-pendula). *Plant and Soil 169:547-553.*

Birch seedlings (Betula pendula) were grown for four months in a greenhouse at three nutrient levels (fertilization of 0, 100 and 500 kg ha(-1) monthly) and at four CO2 concentrations (350, 700, 1050 and 1400 ppm). The effect of CO2 concentration on the biomass production depended on the nutrient status. When mineralization of the soil material was the only source of nutrients (0 kg ha(-1)), CO2 enhancement reduced the biomass production slightly, whereas the highest production increase occurred at a fertilization of 100 kg ha(-1), being over 100% between 350 and 700 ppm CO2. At 500 kg ha(-1) the production increase was smaller, and the production decreased beyond a CO2 concentration of 700 ppm. The CO2 concentration had a slight effect on the biomass distribution, the leaves accounting for the highest proportion at the lowest CO2 concentration (350 ppm). An increase in nutrient status led to a longer growth period and increased the nutrient concentrations in the plants, but the CO2 concentration had no effect on the growth rhythm and higher CO2 reduced the nutrient concentrations.

KEYWORDS: CARBON DIOXIDE, ELEVATED CO2, ENRICHMENT, GROWTH, MARSH, NUTRITION, PHOTOSYNTHESIS, RESPONSES, SIZE, TEMPERATURE

2215
Simard, S.W., D.M. Durall, and M.D. Jones. 1997. Carbon allocation and carbon transfer between Betula papyrifera and Pseudotsuga menziesii seedlings using a C-13 pulse-labeling method. *Plant and Soil 191(1):41-55.*

Here we describe a simple method for pulse-labeling tree seedlings with (CO2(gas)-C-13), and then apply the method in two related experiments: (i) comparison of carbon allocation patterns between Betula papyrifera Marsh. and Pseudotsuga menziesii (Mirb.) France, and (ii) measurement of one-way belowground carbon transfer from B. papyrifera to Fl menziesii. Intraspecific carbon allocation patterns and interspecific carbon transfer both influence resource allocation, and consequently development, in mixed communities of B. papyrifera and P. menziesii. In preparation for the two experiments, we first identified the appropriate (CO2(gas)-C-13) pulse-chase regime for labeling seedlings: a range of pulse (100-mL and 200-mL 99 atom% (CO2(gas)-C-13)) and chase (0, 3 and 6 d) treatments were applied to one year-old B. papyrifera and P. menziesii seedlings. The amount of (CO2)-C-13 fixed immediately after 1.5 h exposure was greatest for both B. papyrifera (40.8 mg excess C-13) and P. menziesii (22.9 mg excess C-13) with the 200-mL pulse, but higher C-13 loss and high sample variability resulted in little difference in excess C-13 content between pulse treatments after 3 d for either species. The average excess C-13 root/shoot ratio of B. papyrifera and P. menziesii changed from 0.00 immediately following the pulse to 0.61 and 0.87 three and six days later, which reflected translocation of 75% of fixed isotope out of foliage within 3 d following the pulse and continued enrichment in fine roots over 6 d. Based on these results, the 100-mL CO2(gas) and 6-d chase were considered appropriate for the carbon allocation and belowground transfer experiments. In the carbon allocation experiment, we found after 6 d that B. papyrifera allocated 49% (average 9.5 mg) and P. menziesii 41% (average 5.8 mg) of fixed isotope to roots, of which over 55% occurred in fine roots in both species. Species differences in isotope allocation patterns paralleled differences in tissue biomass distribution. The greater pulse labeling

efficiency of B. papyrifera compared to P. menziesii was associated with its two-fold and 13-fold greater leaf and whole seedling net photosynthetic rates, respectively, 53% greater biomass, and 35% greater root/shoot ratio. For the carbon transfer experiment, B. papyrifera and P. menziesii were grown together in laboratory rootboxes, with their roots intimately mingled. A pulse of 100 mL (CO2(gas)-C- 13) was applied to paper birch and one-way transfer to neighboring P. menziesii was measured after 6 d. Of the excess C-13 fixed by B. papyrifera, 4.7% was transferred to neighboring P. menziesii, which distributed the isotope evenly between roots and shoots. Of the isotope received by P. menziesii, we estimated that 93% was taken up through belowground pathways, and the remaining 7% taken up by foliage as (CO2(gas)-C-13) respired by B. papyrifera shoots. These two experiments indicate that B. papyrifera fixes more total carbon and allocates a greater proportion to its root system than does Il menziesii, giving it a competitive edge in resource gathering; however, below-ground carbon sharing is of sufficient magnitude that it may help ensure co-existence of the two species in mixed communities.

KEYWORDS: BIRCH, CO2, GROWTH, HYPHAE, PHOTOSYNTHESIS, PLANTS

2216
Simola, L.K., J. Lemmetyinen, and A. Santanen. 1992. Lignin release and photomixotrophism in suspension-cultures of picea-abies. *Physiologia Plantarum 84(3):374-379.*

The effect of different concentrations of sucrose (0-4%) and of two growth regulators (0-50-mu-M 2,4-D and 0-25-mu-M kinetin) was tested on growth and chlorophyll content of suspension cultures of Picea abies (L.) Karst. originating from chlorophyllous embryo callus in an elevated CO2 (2%) atmosphere. A continuous chlorophyllous suspension culture was achieved on a medium containing 2% sucrose and a low level of organic nitrogen (0.25 mM arginine and 0.5 mM glutamine) supplemented with 2,4-D (0.5-mu-M) and kinetin (2.5-mu-M). The same medium with 4% sucrose gave the best growth response, but a negative correlation between chlorophyll level and growth was observed. The chlorophyllous cultures grew slowly in a medium with low (0.5%) sucrose or without any carbohydrate source, suggesting photomixotrophism. A high concentration of kinetin inhibited both growth and chlorophyll synthesis. Release of lignin into the nutrient medium was observed in several experiments, especially in slow-growing cultures supplemented with sucrose. Only a few successive passages of suspensions that produced lignin could be cultured before cell death. The cultures releasing lignin may be unique for studies on synthesis and biodegradation of this very complex compound.

KEYWORDS: CALLUS LINES, CELL-CULTURES, DIFFERENTIATION, ESTABLISHMENT, FINE-STRUCTURE, GROWTH, LIGNIFICATION, MEGAGAMETOPHYTE, NICOTIANA-TABACUM, SPRUCE

2217
Simon, J.P. 1996. Molecular forms and kinetic properties of pyruvate, P-i dikinase from two populations of barnyard grass (Echinochloa crus-galli) from sites of contrasting climates. *Australian Journal of Plant Physiology 23(2):191-199.*

Plants from two populations of the C-4 barnyard grass (Echinochloa crus-galli (L.) Beauv.) from Quebec (QUE) and Mississippi (MISS) were acclimated under controlled conditions to 26/20 and 14/8 degrees C day/night. The apparent energy of activation (E(a)), K-m for pyruvate, V-max/K-m ratios, K-cat (substrate turnover number) and specific activity of pyruvate, P-i dikinase (PPDK, EC 2.7.9.1) were analysed from partially purified Sephadex G-25 extracts of PPDK from leaves and from highly purified PPDK. PPDK from both populations consisted of one isomorph with the same electrophoretic mobility in polyacrylamide gels and similar molecular weights for the native enzyme (385 kDa) and for the subunit of the tetramer (94.8 kDa). No significant differences were observed for any of the kinetic properties of partially purified or purified PPDK or for the specific activity per mg protein of purified PPDK extracted from plants of the two populations and acclimated to the two thermoperiods. Net photosynthetic rates (Ps) were positively correlated with PPDK activity levels (E) but E/Ps ratios were lower than 1.0, ranging from 0.43 to 0.67. Results indicate that differences in activity levels, thermal properties and in the kinetics of light activation and dark inactivation of PPDK extracted from cold-acclimated MISS and QUE plants, as reported in earlier studies, are due to causes other than kinetic properties or electrophoretic characteristics of PPDK.

KEYWORDS: C-4 PHOTOSYNTHESIS, CO2- ENRICHMENT, CRUSGALLI L BEAUV, ECOTYPES, ENZYME LEVEL, HIGHER-PLANTS, NADP+-MALATE DEHYDROGENASE, PHOSPHOENOLPYRUVATE CARBOXYLASE, PURIFICATION, TEMPERATURE

2218
Sims, D.A., W.X. Cheng, Y.Q. Luo, and J.R. Seemann. 1999. Photosynthetic acclimation to elevated CO2 in a sunflower canopy. *Journal of Experimental Botany 50(334):645-653.*

Sunflower canopies were grown in mesocosm gas exchange chambers at ambient and elevated CO2 concentrations (360 and 700 ppm) and leaf photosynthetic capacities measured at several depths within each canopy. Elevated [CO2] had little effect on whole-canopy photosynthetic capacity and total leaf area, but had marked effects on the distribution of photosynthetic capacity and leaf area within the canopy. Elevated [CO2] did not significantly reduce the photosynthetic capacities per unit leaf area of young leaves at the top of the canopy, but it did reduce the photosynthetic capacities of older leaves by as much as 40%. This effect was not dependent on the canopy light environment since elevated [CO2] also reduced the photosynthetic capacities of older leaves exposed to full sun on the south edge of the canopy. In addition to the effects on leaf photosynthetic capacity, elevated [CO2] shifted the distribution of leaf area within the canopy so that more leaf area was concentrated near the top of the canopy. This change resulted in as much as a 50% reduction in photon flux density in the upper portions of the elevated [CO2] canopy relative to the ambient [CO2] canopy, even though there was no significant difference in the total canopy leaf area. This reduction in PFD appeared to account for leaf carbohydrate contents that were actually lower for many of the shaded leaves in the elevated as opposed to the ambient [CO2] canopy. Photosynthetic capacities were not significantly correlated with any of the individual leaf carbohydrate contents, However, there was a strong negative correlation between photosynthetic capacity and the ratio of hexose sugars to sucrose, consistent with the hypothesis that sucrose cycling is a component of the biochemical signalling pathway controlling photosynthetic acclimation to elevated [CO2].

KEYWORDS: ATMOSPHERIC CO2, CARBON-DIOXIDE CONCENTRATION, GAS-EXCHANGE, GENE-EXPRESSION, GROWTH, LEAF, LIGHT, PLANTS, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE, SOYBEAN LEAVES

2219
Sims, D.A., Y. Luo, and J.R. Seemann. 1998. Comparison of photosynthetic acclimation to elevated CO2 and limited nitrogen supply in soybean. *Plant, Cell and Environment 21(9):945-952.*

Plants grown at elevated CO2 often acclimate such that their photosynthetic capacities are reduced relative to ambient CO2- grown plants. Reductions in synthesis of photosynthetic enzymes could result

either from reduced photosynthetic gene expression or from reduced availability of nitrogen-containing substrates for enzyme synthesis. Increased carbohydrate concentrations resulting from increased photosynthetic carbon fixation at elevated CO2 concentrations have been suggested to reduce the expression of photosynthetic genes. However, recent studies have also suggested that nitrogen uptake may be depressed by elevated CO2, or at least that it is not increased enough to keep pace with increased carbohydrate production. This response could induce a nitrogen limitation in elevated-CO2 plants that might account for the reduction in photosynthetic enzyme synthesis. If CO2 acclimation were a response to limited nitrogen uptake, the effects of elevated CO2 and limiting nitrogen supply on photosynthesis and nitrogen allocation should be similar. To test this hypothesis we grew non- nodulating soybeans at two levels each of nitrogen and CO2 concentration and measured leaf nitrogen contents, photosynthetic capacities and Rubisco contents. Both low nitrogen and elevated CO2 reduced nitrogen as a percentage of total leaf dry mass but only low nitrogen supply produced significant decreases in nitrogen as a percentage of leaf structural dry mass. The primary effect of elevated CO2 was to increase non-structural carbohydrate storage rather than to decrease nitrogen content. Both low nitrogen supply and elevated CO2 also decreased carboxylation capacity (V-cmax) and Rubisco content per unit leaf area. However, when V-cmax and Rubisco content were expressed per unit nitrogen, low nitrogen supply generally caused them to increase whereas elevated CO2 generally caused them to decrease. Finally, elevated CO2 significantly increased the ratio of RuBP regeneration capacity to V-cmax whereas neither nitrogen supply nor plant age had a significant effect on this parameter. We conclude that reductions in photosynthetic enzyme synthesis in elevated CO2 appear not to result from limited nitrogen supply but instead may result from feedback inhibition by increased carbohydrate contents.

KEYWORDS: ATMOSPHERIC CO2, C-3 PLANTS, CARBON DIOXIDE, GAS-EXCHANGE, GROWTH, LEAVES, PARTIAL-PRESSURE, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, RUBISCO, SMALL-SUBUNIT

2220

Sims, D.A., Y. Luo, and J.R. Seemann. 1998. Importance of leaf versus whole plant CO2 environment for photosynthetic acclimation. *Plant, Cell and Environment 21(11):1189-1196.*

The reduction of photosynthetic capacity in many plants grown at elevated CO2 is thought to result from a feedback effect of leaf carbohydrates on gene expression, Carbohydrate feedback at elevated CO2 could result from limitations on carbohydrate utilization at many different points, for example export of triose phosphates from the chloroplast, sucrose synthesis and phloem loading, transport in the phloem, unloading of the phloem at the sinks, or utilization for growth of sinks. To determine the relative importance of leaf versus whole plant level limitations on carbohydrate utilization at elevated CO2, and the possible effects on the regulation of photosynthetic capacity, we constructed a treatment system in which we could expose single, attached, soybean leaflets to CO2 concentrations different from those experienced by the rest of the plant. The single leaflet treatments had dramatic effects on the carbohydrate contents of the treated leaflets. However, photosynthetic capacity and rubisco content were unaffected by the individual leaflet treatment and instead were related to the whole plant CO2 environment, despite the fact that the CO2 environment around the rest of the plant had no significant affect on the total non-structural carbohydrate (TNC) contents of the treated leaflets. These results necessitate a re- evaluation of the response mechanisms to CO2 as well as some of the methods used to test these responses. We propose mechanisms by which sink strength could influence leaf physiology independently of changes in carbohydrate accumulation.

KEYWORDS: CARBON ASSIMILATION, ELEVATED CO2, GAS-EXCHANGE, GENE-EXPRESSION, IN-BAG EXPERIMENT, LEAVES, PHLOEM TRANSPORT, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE, SCOTS PINE, SINK REGULATION

2221

Sims, D.A., J.R. Seemann, and Y. Luo. 1998. The significance of differences in the mechanisms of photosynthetic acclimation to light, nitrogen and CO2 for return on investment in leaves. *Functional Ecology 12(2):185-194.*

1. We report changes in photosynthetic capacity of leaves developed in varying photon flux density (PFD), nitrogen supply and CO2 concentration. We determined the relative effect of these environmental factors on photosynthetic capacity per unit leaf volume as well as the volume of tissue per unit leaf area. We calculated resource-use efficiencies from the photosynthetic capacities and measurements of leaf dry mass, carbohydrates and nitrogen content. 2. There were clear differences between the mechanisms of photosynthetic acclimation to PFD, nitrogen supply and CO2. PFD primarily affected volume of tissue per unit area whereas nitrogen supply primarily affected photosynthetic capacity per unit volume. CO2 concentration affected both of these parameters and interacted strongly with the PFD and nitrogen treatments. 3. Photosynthetic capacity per unit carbon invested in leaves increased in the low PFD, high nitrogen and low CO2 treatments. Photosynthetic capacity per unit nitrogen was significantly affected only by nitrogen supply. 4. The responses to low PFD and low nitrogen appear to function to increase the efficiency of utilization of the limiting resource. However, the responses to elevated CO2 in the high PFD and high nitrogen treatments suggest that high CO2 can result in a situation where growth is not limited by either carbon or nitrogen supply. Limitation of growth at elevated CO2 appears to result from internal plant factors that limit utilization of carbohydrates at sinks and/or transport of carbohydrates to sinks.

KEYWORDS: ALOCASIA-MACRORRHIZA, C-3 PLANTS, CARBON BALANCE, ELEVATED CO2, ENRICHMENT, GROWTH, LEAF ANATOMY, PHOTON FLUX DENSITIES, SCALING SUN, WHOLE-PLANT PERFORMANCE

2222

Sims, D.A., J.R. Seemann, and Y.Q. Luo. 1998. Elevated CO2 concentration has independent effects on expansion rates and thickness of soybean leaves across light and nitrogen gradients. *Journal of Experimental Botany 49(320):583-591.*

The rate and extent of leaf thickness and development are important determinants of plant photosynthetic capacity, The interactive effects of photon flux density (PFD), nitrogen supply and CO2 concentration on leaf expansion rate were measured as well as final leaf size and thickness of soybean, Leaf thickness and final area were not correlated with leaf relative expansion rate (RER) suggesting that these parameters are controlled by different mechanisms and that final leaf dimensions are determined by the duration rather than the rate of leaf expansion, Carbohydrate supply did not explain the variation ii? leaf RER since RER increased with increasing CO2 concentration, but decreased with increasing PFD. Leaf thickness and final area were related to resource supply but not in a simple fashion, Both positive and negative correlations between leaf thickness and carbohydrate and nitrogen concentrations were obtained depending on the environmental variable responsible for the variation. In contrast, there was a simple proportional relationship between whole plant relative growth rate and a correlate of leaf thickness (leaf water content per unit area), suggesting that leaf thickness responds to the balanced supply of all resources, in the same fashion as RGR, rather than to any individual resource.

KEYWORDS: ACCLIMATION, ANATOMY, CARBON, ENRICHMENT,

LEAF GROWTH, PHASEOLUS-VULGARIS, PHOTOSYNTHESIS, PLANTS, TEMPERATURE, WATER RELATIONS

2223
Sinclair, T.R. 1992. Mineral-nutrition and plant-growth response to climate change. *Journal of Experimental Botany 43(253):1141-1146.*

The limiting factor concept has often been used to describe plant growth responses to altered availability of resources. However, even preliminary experiments, where atmospheric CO2 concentrations and solution mineral concentrations were varied, demonstrated that a more complex concept was required to interpret the potential effects of climate change and mineral availability on plant growth. It is proposed that these resources for plant growth may be better viewed as simultaneously limiting. Further, in considering the limitation in plant growth to mineral nutrition it is important to consider both the solution concentration and the total amount of the individual minerals available to the plant. Sustaining a positive response to increased CO2 concentration, for example, requires an increase in plant uptake of the total amount of minerals. Consequently, it is very difficult to predict the plant growth response to climate change because of the large uncertainty about mineral availability. On the one hand, increased CO2 concentrations should stimulate nitrogen fixation by both free-living organisms and symbiotic systems, and improve soil properties for mineral availability as a result of increased organic matter deposition in the soil. On the other hand, increased temperature and altered rainfall patterns may result in increased losses of soil minerals. Even the direction in the net change in available soil minerals is unclear. Realistic evaluations of the effects of climate change on plant growth will be challenged to contend with the large uncertainty and complexities in understanding mineral availability and plant mineral nutrition.

KEYWORDS: CARBON-DIOXIDE ENRICHMENT, CO2-ENRICHMENT, NET NITROGEN MINERALIZATION, ROOT NODULE ACTIVITY, SEED YIELD, SOILS

2224
Sinclair, T.R., and N.G. Seligman. 1995. Global environment change and simulated forage quality of wheat .1. Nonstressed conditions. *Field Crops Research 40(1):19-27.*

Projected changes in the global environment may affect both the quantity and quality of grain and forage mass produced and harvested in that environment. Quality is a major factor in determining the value of a forage crop as feed for ruminants. The objective of this study was to make a preliminary assessment of potential changes in the quantity and quality of forage as measured by [N] and leaf:stem of an annual, temperate climate C-3 forage crop grown under nonstressed conditions. Starting with a relatively simple, well-checked mechanistic model of wheat, adaptations were added to estimate changes in forage attributes. Increased temperature influenced both yield and nutritive value, mainly through changes in ontological development rates. Elevated,atmospheric [CO2] resulted in greater mass accumulation, but with lower leaf:stem and [N]. The combined effect of increased temperature and elevated [CO2] was to decrease slightly forage yield and to increase the forage nutritive value. These compensating effects of higher temperature and elevated [CO2] could be modified by interactions between [CO2] and the chemical composition and cell wall structure of forage plants. Analysis of such subtle interaction requires considerable experimental amplification.

KEYWORDS: CARBON DIOXIDE, CO2- ENRICHMENT, DRY-MATTER, ELEVATED CO2, GROWTH, NITROGEN, SPRING WHEAT, TEMPERATURE, WINTER-WHEAT, YIELD

2225
Singer, A., A. Eshel, M. Agami, and S. Beer. 1994. The contribution of aerenchymal co2 to the photosynthesis of emergent and submerged culms of scirpus-lacustris and cyperus- papyrus. *Aquatic Botany 49(2-3):107-116.*

In this work it was investigated whether sediment-derived aerenchymal CO2 could be utilized for photosynthesis in the culms of the two emergent aquatic macrophytes Scirpus lacustris L. (a C-3 plant) and Cyperus papyrus L. (a C-4 plant). Aerenchymal CO2 concentrations within the submerged parts of the culms were found to be 30 000-50 000, mu l l(-1), and ca. 800 mu l l(-1) in the emergent parts of Scirpus lacustris and 2000 mu l l(-1) in Cyperus papyrus. These concentrations tended to be lower during the day in Cyperus, while no dear diurnal pattern was observed for Scirpus. Photosynthetic rates based on fixation of external or internal CO2 were measured in situ by providing (CO2)-C-14 either externally or from the aerenchyma (by supplying C-14-labelled CO2 through test-tubes attached to excised culms). The results showed that the contribution of aerenchymal CO2 to the total photosynthesis of emergent culms was less than 0.25% in both species. This has a rationale in that photosynthetic rates of both species were saturated at the ambient air CO2 concentration, but it remains unclear why CO2 does not diffuse towards the photosynthesizing tissues. By contrast, internal CO2 appeared to be the only source of inorganic carbon used for photosynthesis of young submerged green culms. It is thus suggested that the aerenchyma, in addition to other functions, is important in providing sediment-derived CO2 for photosynthesis in young shoots or culms if growing submerged, before they reach the water surface.

KEYWORDS: CARBON, ELEVATED ATMOSPHERIC CO2, FLOW, TRIN EX STEUD

2226
Singh, B., and R.B. Stewart. 1991. Potential impacts of a CO2-induced climate change using the GISS scenario on agriculture in quebec, canada. *Agriculture Ecosystems & Environment 35(4):327-347.*

This study examines the potential impacts of a climate change resulting from an effective doubling of atmospheric CO2 on the potential and anticipated yields of a variety of agricultural crops including corn, soya, potatoes, wheat, phaseolus beans, sorghum, barley, oats, rapeseed and sunflowers and two horticultural crops namely apples and grapes, for southern Quebec. The GISS climate change scenario is used. Our results show that yields would increase for some crops such as corn, soybeans, potatoes, phaseolus beans and sorghum and would decrease for the cereal and oilseed crops, namely wheat, barley, oats, sunflowers and rapeseed. Production opportunities for apples and grapes are enhanced. Also it would seem that the more northerly regions of Abitibi-Temiscamingue and Lac St-Jean would benefit most, in terms of agriculture, from a CO2-induced climate change.

KEYWORDS: BALANCE, CARBON DIOXIDE, CO2, COMPONENTS, CROP, CYCLE, GENERAL-CIRCULATION MODEL, SENSITIVITY, WHEAT, YIELD

2227
Singh, T., and E.E. Wheaton. 1991. Boreal forest sensitivity to global warming - implications for forest management in western interior canada. *The Forestry Chronicle 67(4):342-348.*

Unmitigated global warming due to the enhanced greenhouse effect could have significant impacts on the boreal forest in interior western Canada. Increases in annual temperature of 3 to 7-degrees-C are projected for Alberta under a 2 x CO2 scenario by 2030-2050 A.D. Such an unprecedented rate of change has many short- and long-term

implications for forest management and for industries. As the boreal forest is highly sensitive to climatic changes, foresters need to develop a set of safe strategies to minimize the negative impacts and maximize the benefits of these changes.

2228

Slafer, G.A. 1995. Wheat development as affected by radiation at two temperatures. *Journal of Agronomy and Crop Science-Zeitschrift Fur Acker Und Pflanzenbau 175(4):249-263.*

A wheat cultivar (Condor) was grown in two experiments (thermal regimes 18/13 and 21/16 degrees C) under low (298 mu E m(-2) s(-1)) radiation regimes during either an early phase from seedling emergence to terminal spikelet initiation (S-1), a late phase from terminal spikelet initiation to anthesis (S-2), or for the full period from seedling emergence to anthesis (S- 12), or high (560 mu E m(-2) s(-1)) radiation throughout the growing period (S-0) to determine whether developmental events are affected by radiation. The main developmental events considered in this study were the timing of terminal spikelet initiation and anthesis, the final number of leaf and spikeler primordia initiated in the apex and the rare of leaf appearance. Number of grains per spike and culm height were also measured. The duration of each phenophase was not affected by radiation intensity. Temperature affected the rate of wheat development, but the acceleration of development due to temperature during the seedling emergence-terminal spikelet initiation phase only slightly reduced (from 24.8 to 23.2 days). Differences in time from terminal spikelet initiation to anthesis were greater than in the earlier phases, having been the duration reduced from 24.6 to 20.0 days due to high temperature. Associated with the lack of effect of radiation on phasic development and the negligible effect of temperature on the duration of the early phases of development, final leaf number was practically unchanged in this study by either the radiation level or the growing temperature. Thus, radiation did not affect the rate of leaf initiation. The number of spikelets was affected by neither the treatments nor the thermal environment. The rates of leaf appearance were accelerated by temperature. Radiation, on the other hand, did nor significantly alter the rates of leaf appearance in any of the treatments. As expected from many sources in the literature, the number of grains per spike was significantly affected by radiation during the phase from terminal spikelet initiation to anthesis. Due to the lack of significant effects of radiation on the developmental patterns of wheat, the changes in number of grains per spike were due to changes in the number of grains born in each spikelet. The results of the present study were compared with others available in the literature on the effects (or lack of them) of radiation and CO2 concentration on phasic development, plastochron and phyllochron in wheat to reach the general conclusion that the rate of developmental events in wheat, in contrast to other plants, is almost completely independent of the availability of assimilates, with a possible exception for the Equatorial latitudes.

KEYWORDS: BASE TEMPERATURE, CARBON-DIOXIDE ENRICHMENT, CO2- ENRICHMENT, GRAIN-YIELD, GROWTH, PHOTOPERIOD, SPIKELET NUMBER, SPRING WHEAT, WATER-STRESS, WINTER-WHEAT

2229

Slafer, G.A., and H.M. Rawson. 1997. CO2 effects on phasic development, leaf number and rate of leaf appearance in wheat. *Annals of Botany 79(1):75-81.*

It has been predicted that the concentration of CO2 in the air could double during the 21st century. Though it is recognized that CO2-doubling could increase yield through its effects on plant photosynthesis and stomatal behaviour, it is unclear whether CO2-doubling will change phasic development in wheat. A phytotron study was conducted with two contrasting cultivars of wheat, Condor (spring) and Cappelle Desprez (winter), to determine whether development is affected by a season-long exposure to 360 and 720 ppmv CO2. Plants were vernalized for 50 d (8/4 degrees C, s h photoperiod) before their exposure to the CO2 treatments. There were significant differences between cultivars in the duration of different phenophases as well as in the final number of leaves. However, CO2 concentration had no effect in either cultivar on the duration of the early developmental phase to terminal spikelet initiation, or on the final number of leaves, though CO2-doubling did slightly increase the later phase from terminal spikelet initiation to heading in Cappelle Desprez. Condor and Cappelle Desprez also differed markedly in the dynamics of leaf appearance. While the former had a constant rate of leaf appearance throughout development, the latter had a fast rate initially (between leaves 1 and 7), similar to that of Condor, which was followed by a slower rate after the appearance of leaf 7. Overall, CO2- doubling did not significantly affect the rates of leaf appearance nor the shape of the relationship. Phyllochron for the first seven leaves was the same for both CO2 concentrations. However, the change in phyllochron associated with CO2-doubling for leaves 7-12 in Cappelle Desprez, although quite small (4%), accounts for part of the slightly increased duration of the phase from terminal spikelet initiation to heading under high CO2 concentration in that cultivar. We conclude that CO2 concentration does not influence development in wheat to a degree relevant to agronomy. (C) 1997 Annals of Botany Company

KEYWORDS: ATMOSPHERIC CO2, BASIC DEVELOPMENT RATE, CARBON-DIOXIDE ENRICHMENT, ELEVATED CO2, GROWTH, PHOTOPERIOD, SOWING DATE, SPRING WHEAT, TEMPERATURE, WINTER-WHEAT

2230

Smart, D.R., N.J. Chatterton, and B. Bugbee. 1994. The influence of elevated co2 on nonstructural carbohydrate distribution and fructan accumulation in wheat canopies. *Plant, Cell and Environment 17(4):435-442.*

We grew 2.4 m2 wheat canopies in a large growth chamber under high photosynthetic photon flux (1000 mumol m-2 s-1) and using two CO2 concentrations, 360 and 1200 mumol mol-1. Photosynthetically active radiation (400-700 nm) was attenuated slightly faster through canopies grown in 360 mumol mol-1 than through canopies grown in 1200 mumol mol-1, even though high- CO2 canopies attained larger leaf area indices. Tissue fractions were sampled from each 5-cm layer of the canopies. Leaf tissue sampled from the tops of canopies grown in 1200 mumol mol-1 accumulated significantly more total non-structural carbohydrate, starch, fructan, sucrose, and glucose (p less- than-or-equal-to 0-05) than for canopies grown in 360 mumol mol-1. Non-structural carbohydrate did not significantly increase in the lower canopy layers of the elevated CO2 treatment. Elevated CO2 induced fructan synthesis in all leaf tissue fractions, but fructan formation was greatest in the uppermost leaf area. A moderate temperature reduction of 10-degrees-C over 5 d increased starch, fructan and glucose levels in canopies grown in 1200 mumol mol-1, but concentrations of sucrose and fructose decreased slightly or remained unchanged. Those results may correspond with the use of fructosyl-residues and release of glucose when sucrose is consumed in fructan synthesis.

KEYWORDS: CARBON DIOXIDE, LEAVES, LOLIUM-TEMULENTUM L, METABOLISM, PHOTOSYNTHESIS, PLANTS, RESPIRATION, SUCROSE, TEMPERATURES

2231

Smart, D.R., K. Ritchie, A.J. Bloom, and B.B. Bugbee. 1998. Nitrogen balance for wheat canopies (Triticum aestivum cv. Veery 10) grown under elevated and ambient CO2 concentrations. *Plant, Cell and Environment 21(8):753-763.*

We examined the hypothesis that elevated CO2 concentration would increase NO3- absorption and assimilation using intact wheat canopies (Triticum aestivum cv, Veery 10), Nitrate consumption, the sum of plant absorption and nitrogen loss, was continuously monitored for 23 d following germination under two CO2 concentrations (360 and 1000 mu mol mol(-1) CO2) and two root zone NO3- concentrations (100 and 1000 mmol m(3) NO3-). The plants were grown at high density (1780 m(-2)) in a 28 m3 controlled environment chamber using solution culture techniques. Wheat responded to 1000 mu mol mol(-1) CO2 by increasing carbon allocation to root biomass production. Elevated CO2 also increased root zone NO3- consumption, but most of this increase did not result in higher biomass nitrogen. Rather, nitrogen loss accounted for the greatest part of the difference in NO3- consumption between the elevated and ambient [CO2] treatments. The total amount of NO3--N absorbed by roots or the amount of NO3--N assimilated per unit area did not significantly differ between elevated and ambient [CO2] treatments. Instead, specific leaf organic nitrogen content declined, and NO3- accumulated in canopies growing under 1000 mu mol mol(-1) CO2. Our results indicated that 1000 mu mol mol(-1) CO2 diminished NO3- assimilation. If NO3- assimilation were impaired by high [CO2], then this offers an explanation for why organic nitrogen contents are often observed to decline in elevated [CO2] environments.

KEYWORDS: ASSIMILATION, ATMOSPHERIC CO2, BARLEY, CARBON-DIOXIDE ENRICHMENT, LEAVES, NITRATE REDUCTASE-ACTIVITY, PLANT GROWTH, TEMPERATURE, TOMATO, WINTER-WHEAT

2232

Smart, D.R., K. Ritchie, J.M. Stark, and B. Bugbee. 1997. Evidence that elevated CO2 levels can indirectly increase rhizosphere denitrifier activity. *Applied and Environmental Microbiology 63(11):4621-4624.*

We examined the influence of elevated CO2 concentration on denitrifier enzyme activity in wheat rhizoplanes by using controlled environments and solution culture techniques. Potential denitrification activity was from 3 to 24 times higher on roots that were grown under an elevated CO2 concentration of 1,000 mu mol of CO2 mol(-1) than on roots grown under ambient levels of CO2. Nitrogen loss, as determined by a nitrogen mass balance, increased with elevated CO2 levels in the shoot environment and with a high NO3- concentration in the rooting zone. These results indicated that aerial CO2 concentration can play a role in rhizosphere denitrifier activity.

KEYWORDS: AMMONIA, ENVIRONMENT, EXCHANGE, PLANTS, RICE, SOIL DENITRIFICATION, WHEAT

2233

Smeekens, S. 1998. Sugar regulation of gene expression in plants. *Current Opinion in Plant Biology 1(3):230-234.*

The molecular details of sugar sensing and sugar-mediated signal transduction pathways are unclear but recent results suggest that hexokinase functions as an important plant sugar sensor in a way that is similar to that found in yeast. The use of mutants in Arabidopsis defective in specific signaling steps is of particular importance because these give access to the genes encoding components in the signaling pathways. In addition, the physiological analysis of such mutants may reveal the interaction of sugar-induced signaling pathways and those induced by other stimuli such as environmental or biotic stress.

KEYWORDS: ARABIDOPSIS-THALIANA, BETA-AMYLASE, CHENOPODIUM-RUBRUM, ELEVATED CO2, GLUCOSE, INVERTASE, SACCHAROMYCES- CEREVISIAE, SIGNAL-TRANSDUCTION, SUCROSE EXPORT, TISSUE-SPECIFIC EXPRESSION

2234

Smernoff, D.T., J. Gale, B.A. Macler, and J. Reuveni. 1993. Inhibition of photosynthesis in duckweed by elevated co2 concentration is rapid and is not offset by a temperature- induced increase in metabolic-rate. *Photosynthetica 28(1):17-28.*

The rates of net photosynthesis (P(N)), respiration and growth of Lemna gibba L. were measured as functions of time across ranges of temperature, irradiance and carbon dioxide concentrations. P(N) on an area basis increased with temperature up to 30-degrees-C but decreased dramatically with a few hours of exposure to elevated CO2, when reported on a dry mass basis. Reductions in the apparent quantum efficiency, photosynthetic capacity and the affinity of ribulose- 1,5-bisphosphate carboxylase/oxygenase for CO2 were observed for plants grown at elevated CO2. Starch concentration was not significantly affected by elevated CO2. Although elevated temperature increased metabolic activity, it only partially alleviated the inhibition of P(N). L. gibba exhibits a characteristic C3-type response to elevated CO2 and the methodology described is useful for further elucidating the mechanism of photosynthetic acclimation to elevated CO2.

KEYWORDS: ACCLIMATION, CARBON DIOXIDE, CARBOXYLASE, CULTIVATION, DESERT CONDITIONS, ENRICHMENT, GROWTH, HIGH ATMOSPHERIC CO2, LEMNA-GIBBA, PHOTORESPIRATION

2235

Smit, B., and Y.L. Cai. 1996. Climate change and agriculture in China. *Global Environmental Change-Human and Policy Dimensions 6(3):205-214.*

The implications of climate change for agriculture and food are global concerns, and they are very important for China, The country depends on an agricultural system which has evolved over thousands of years to intensively exploit environmental conditions. The pressures on the resource base are accentuated by the prospect of climate change, This paper synthesizes information from a variety of studies on Chinese agriculture and climate. Historical studies document the impacts of past climate changes and extremes, and the types of adjustments which have occurred, the vulnerability of Chinese agriculture to climate change, Climate change scenarios are assessed relative to the current distribution of agro-climatic regions and systems, Notwithstanding the enhancing effects of warming and elevated CO2 levels, expected moisture deficits and uncertain changes in the timing and frequency of critical conditions indicate that there are serious threats to the stability and adaptability of China's food production system. Copyright (C) 1996 Elsevier Science Ltd

2236

Smith, P.H.D., and T.H. Jones. 1998. Effects of elevated CO2 on the chrysanthemum leafminer, Chromatomyia syngenesiae: a greenhouse study. *Global Change Biology 4(3):287-291.*

Although feeding behaviour of Chromatomyia syngenesiae on plants grown in elevated CO2 (ambient + 200ppm) was unaffected, leaf-miner development was slower in elevated compared to ambient CO2 atmospheres. Pupal weight was lower at high CO2 and correlated with the area of leaf mined; no such correlation existed in ambient CO2. There appears to be no compensatory feeding by the leaf-miner for the reduced food quality of plants growing in elevated CO2. The implications of these findings are discussed.

KEYWORDS: HERBIVORE INTERACTIONS

2237
Smith, R.B. 1992. Controlled-atmosphere storage of redcoat strawberry fruit. *Journal of the American Society for Horticultural Science 117(2):260-264.*

Strawberries (Fragaria x ananassa Duch.) cv. Redcoat were stored at several temperatures and for various intervals in controlled atmospheres (CA) containing 0% to 18% CO2 and 15% to 21% O2. Bioyield point forces recorded on the CA-stored fresh fruit indicated that the addition of CO2 to the storage environment enhanced fruit firmness. Fruit kept under 15% CO2 for 18 hours was 48% firmer than untreated samples were initially. Response to increasing CO2 concentrations was linear. There was no response to changing O2 concentrations. Maximum enhancement of firmness was achieved at a fruit temperature of 0C; there was essentially no enhancement at 21C. In some instances, there was a moderate firmness enhancement as time in storage increased. Carbon dioxide acted to reduce the quantity of fruit lost due to rot. Fruit that was soft and bruised after harvest became drier and firmer in a CO2-enriched environment.

KEYWORDS: DECAY, QUALITY

2238
Smith, R.B., and L.J. Skog. 1992. Postharvest carbon-dioxide treatment enhances firmness of several cultivars of strawberry. *Hortscience 27(5):420-421.*

Various cultivars of strawberry (Fragaria xananassa Duch.) were stored for 42 h under an atmosphere of 15% CO2 to determine whether their firmness would be enhanced. Compared to initial samples and stored control samples, enhanced firmness was found in 21 of the 25 cultivars evaluated. The CO2 had no effect on color, as measured by Hunter 'L', 'a' and 'b', or on soluble solids concentration (SSC) or pH. There were significant differences among cultivars in firmness; Hunter color 'L', 'a', and 'b'; SSC; and pH.

KEYWORDS: ATMOSPHERES, QUALITY

2239
Smith, T.M., W.P. Cramer, R.K. Dixon, R. Leemans, R.P. Neilson, and A.M. Solomon. 1993. The global terrestrial carbon-cycle. *Water, Air, and Soil Pollution 70(1-4):19-37.*

There is great uncertainty with regard to the future role of the terrestrial biosphere in the global carbon cycle. The uncertainty arises from both an inadequate understanding of current pools and fluxes as well as the potential effects of rising atmospheric concentrations of CO2 on natural ecosystems. Despite these limitations, a number of studies have estimated current and future patterns of terrestrial carbon storage. Future estimates focus on the effects of a climate change associated with a doubled atmospheric concentration of CO2. Available models for examining the dynamics of terrestrial carbon storage and the potential role of forest management and landuse practices on carbon conservation and sequestration are discussed.

KEYWORDS: CLIMATE CHANGE, ECOSYSTEMS, ELEVATED CO2 CONCENTRATIONS, ESTUARINE MARSH, FORESTS, GENERAL-CIRCULATION MODEL, INCREASE, SENSITIVITY, SOILS, STORAGE

2240
Smith, T.M., R. Leemans, and H.H. Shugart. 1992. Sensitivity of terrestrial carbon storage to co2-induced climate change - comparison of 4 scenarios based on general- circulation models. *Climatic Change 21(4):367-384.*

The potential impacts of CO2-induced climate change on terrestrial carbon storage was estimated using the Holdridge Life-Zone Classification and four climate change scenarios derived from general circulation models. Carbon values were assigned to life-zones and their associated soils from published studies. All four scenarios suggest an increase in area occupied by forests although details of predicted patterns vary among the scenarios. There is a poleward shift of the forested zones, with an increase in the areal extent of tropical forests and a shift of the boreal forest zone into the region currently occupied by tundra. Terrestrial carbon storage increased from 0.4% (8.5 Gt) to 9.5% (180.5 Gt) above estimates for present conditions. These changes represent a potential reduction of 4 to 85 ppm on elevated atmospheric CO2 levels.

KEYWORDS: CO2, INCREASE

2241
Smith, W.K., and R.A. Donahue. 1991. Simulated influence of altitude on photosynthetic CO2 uptake potential in plants. *Plant, Cell and Environment 14(1):133-136.*

A simulation of the quantitative influence of altitude on photosynthetic CO2 uptake capability (A(P)) included the effects of predicted changes (1) in air temperature (lapse rate) and (2) leaf temperature, (3) ambient pressure and CO2 concentration, and (4) the diffusion coefficient for CO2 in air. When a dry lapse rate (0.01-degrees-C m-1) in air temperature was simulated, significant declines (up to 14%) in A(P) were predicted from sea level to 4km altitude. A moist lapse rate of 0.003-degrees-C m-1 resulted in less than a 4% decrease in A(P) over the same altitude range. When natural leaf temperatures (predicted from heat balance analyses) were simulated, A(P) was significantly greater (almost-equal-to 20%) than when leaf temperatures were considered equal to air temperature for all lapse conditions. There was virtually no change in A(P) with altitude when predicted leaf temperatures and moist lapse conditions were simulated. There was a significant (almost-equal-to 10%) increase in A(P) with altitude when leaf temperature was held constant at 30-degrees- C (regardless of altitude) under moist lapse conditions. Future studies evaluating the effects of elevation on photosynthesis could benefit from the above considerations of the effects of natural leaf temperature regimes and prevailing lapse conditions on CO2 uptake potential.

KEYWORDS: CONDUCTANCE, LEAF ANATOMY

2242
Socias, F.X., H. Medrano, and T.D. Sharkey. 1993. Feedback limitation of photosynthesis of phaseolus-vulgaris L grown in elevated co2. *Plant, Cell and Environment 16(1):81-86.*

The capacity for photosynthesis is often affected when plants are grown in air with elevated CO2 partial pressure. We grew Phaseolus vulgaris L. in 35 and 65Pa CO2 and measured photosynthetic parameters. When assayed at the growth CO2 level, photosynthesis was equal in the two CO2 treatments. The maximum rate of ribulose-1,5-bisphosphate (RuBP) consumption was lower in plants grown at 65Pa, but the CO2 partial pressure at which the maximum occurred was higher in the high-CO2-grown plants, indicating acclimation to high CO2. The acclimation of RuBP consumption to CO2 involved a reduction of the activity of RuBP carboxylase which resulted from reduced carbamylation, not a loss of protein. The rate of RuBP consumption declined with CO2 when the CO2 partial pressure was above 50Pa in plants grown under both CO2 levels. This was caused by feedback inhibition as judged by a lack of response to removing O2 from the air stream. The rate of photosynthesis at high CO2 was lower in the high-CO2-grown plants and this was correlated with reduced activity of sucrose-phosphate synthase. This is only the second report Of O2-insensitive

photosynthesis under growth conditions for plants grown in high CO2.

KEYWORDS: ACCLIMATION, CARBON DIOXIDE, GAS-EXCHANGE, ISOPRENE EMISSION, LEAVES, PHOTORESPIRATION, PLANTS, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, RUBISCO, SUCROSE PHOSPHATE SYNTHASE

2243

Solarova, J., and J. Pospisilova. 1997. Effect of carbon dioxide enrichment during in vitro cultivation and acclimation to ex vitro conditions. *Biologia Plantarum 39(1):23-30.*

Tobacco and carnation plantlets were grown in vitro on Murashige and Skoog's medium with 2% saccharose. Carnation plantlets were also grown fully photoautotrophically on a medium without saccharose. The ambient CO2 concentration was increased from 0.6 to 10 or 40 g m(-3) during the last 3 weeks of in vitro cultivation or during the first 3 weeks of acclimation to ex vitro condition (plantlets transplanted to pots with sand and nutrient solution) or during both growth phases. CO2 enrichment during in vitro cultivation markedly stimulated growth of tobacco plantlets, and also of carnation plantlets, both with and without saccharose. CO2 enrichment during the acclimation period promoted plant growth more effectively in plantlets grown in vitro at a CO2 concentration of 0.6 g m(-3) than in plantlets grown in either growth phase at higher CO2 concentrations.

KEYWORDS: CO2- ENRICHMENT, GROWTH, INVITRO, PHOTOSYNTHESIS, PLANTLETS, RASPBERRY, STRAWBERRY

2244

Sombroek, W.G., F.O. Nachtergaele, and A. Hebel. 1993. Amounts, dynamics and sequestering of carbon in tropical and subtropical soils. *Ambio 22(7):417-426.*

The organic carbon pool in the upper 1 m of the world's soils contains 1220 Gt organic carbon, 1.5 times the total for the standing biomass. In the widespread deep soils in the tropics the carbon stored below 1 m may add about 50 Gt C. The contributions of charcoal, roots and soil fauna should be added to these totals. The much less dynamic carbonate-carbon pool amounts to 720 Gt C. Changes in land use, particularly by clearing of forests, reduce organic carbon by 20 to 50% in the upper soil layers, but little in deeper layers. On the other hand, there are indications that a human-induced enrichment of soil organic matter can be maintained over centuries. Research on the causative soil processes should be supported, because an improved understanding of this phenomenon might lead to better management strategies and sound programs to stimulate organic carbon storage and fertility levels in tropical and subtropical soils. Recent research data on the CO2 fertilization effect and the associated antitranspiration effect due to an increase of CO2 in the atmosphere indicate that a positive influence on soil organic carbon levels can be expected.

KEYWORDS: AMAZON, BIOMASS, BIOSPHERE, CYCLE, FORESTS, STORAGE

2245

Sommerfeld, R.A., W.J. Massman, R.C. Musselman, and A.R. Mosier. 1996. Diffusional flux of CO2 through snow: Spatial and temporal variability among alpine-subalpine sites. *Global Biogeochemical Cycles 10(3):473-482.*

Three alpine and three subalpine sites were monitored for up to 4 years to acquire data on the temporal and spatial variability of CO2 flux through snowpacks. We conclude that the snow formed a passive cap which controlled the concentration of CO2 at the snow-soil interface, while the flux of CO2 into the atmosphere was controlled by CO2 production in the soil. Seasonal variability in the flux at all sites was characterized by early winter minima followed by a rise in flux that averaged 70% above the minima over about a I-month period. The seasonal variability was not related to soil temperatures which remained relatively constant. Interannual variability was small, and spatial variability was smaller than previously reported. Spatial variability on a scale of 1 to 10 m was less than 30% of the average fluxes and not significantly greater than estimated error in most cases. Spatial variability on a scale of 10- to 100-m was about a factor of 2 and on a scale of 100 to 1000 m was about a factor of 4. The 100- to 1000-m variability was complicated by the fact that the sites were in different ecosystems, alpine and subalpine, and at different elevations. We attribute the small variability at the 1- to 10- m scale to the deep snow cover, from 1.4 to 5 m. We hypothesize that horizontal diffusion under the snow cover reduced small- scale horizontal gradients, while the insulating effect of the deep snow cover kept the soil temperature and moisture relatively constant. Equivalent annual wintertime flux averaged about 95 g C m(-2) yr(-1) in the alpine and about 232 g C m(-2) yr(-1) in the subalpine sites. Measurements of CO2 concentrations at 0.2 and 0.5 m in the soil of one of the subalpine sites indicated that production early in the snow season occurred at or below 0.5 m while production between 0.5 m, and the surface became important after the start of the melt season.

KEYWORDS: SOILS

2246

Sonesson, M., T.V. Callaghan, and L.O. Bjorn. 1995. Short-term effects of enhanced UV-B and CO2 on lichens at different latitudes. *Lichenologist 27:547-557.*

Interaction effects of UV-B and CO2 on three lichens species, Cladonia arbuscula, Cetraria islandica and Stereocaulon paschale, from two latitudinal sites, 68 degrees N and 56 degrees N, were studied in a laboratory experiment. The response of the plants was recorded by measuring their chlorophyll fluorescence. All species had a similar response to enhanced UV-B depending on the latitude from which the population came and the time of the season when they were sampled. Overall, there was a significant increase in photosystem II yield (as measured by a fluorescence technique) due to UV-B and no separate effect due to enhanced CO2, although there was a significant interaction between CO2 and UV-B. The increase due to UV-B was at the low CO2 level. There were also significant differences in response due to latitude. The results contradict our hypotheses that negative effects of UV-B would be larger in the North than in the South and that a negative response should be especially large during the early season. (C) 1995 The British Lichen Society

KEYWORDS: ALPINE LIFE ZONE, BLUE-GREEN PHYCOBIONTS, CARBON DIOXIDE, CHLOROPHYLL FLUORESCENCE, GROWTH, MARINE DIATOMS, PHOTOSYNTHETIC CHARACTERISTICS, PLANTS, RADIATION, STRATOSPHERIC OZONE

2247

Sonesson, M., T.V. Callaghan, and B.A. Carlsson. 1996. Effects of enhanced ultraviolet radiation and carbon dioxide concentration on the moss Hylocomium splendens. *Global Change Biology 2(1):67-73.*

In a laboratory experiment interaction effects of UV-B and CO2 on photosynthesis and growth of the moss Hylocomium splendens were studied. The plants were exposed to two CO2 levels (350 ppm and 600 ppm) and three UV-B levels (no UV-B, ambient UV-B and that corresponding to 20% ozone depletion) for 5 months. The effects were recorded by measuring the photosynthetic response and growth of the plants. There was a statistically significant change in photosynthetic

efficiency and maximum photosynthetic rates due to time and to enhanced CO2 concentration, whereas there was no effect due to UV-B. There was a decreased growth due to both UV-B and CO2 and an interaction effect on growth (in length). The UV-B dose corresponding to the ambient level had a larger reducing effect on growth than the highest UV-B dose. This was a counter- intuitive result and the following tentative interpretation was made: differences in the measured UV-A/UV-B/PAR ratios between the treatments could explain the result provided there was a non-linear response to UV over the range of irradiance levels used.

KEYWORDS: ACTION SPECTRUM, CO2, DAMAGE, GROWTH, IRRADIATION, LIGHT, MARINE DIATOMS, PHOTOSYNTHETIC CHARACTERISTICS, PLANTS, UV-B RADIATION

2248

Soule, P.T., and P.A. Knapp. 1999. Western juniper expansion on adjacent disturbed and near-relict sites. *Journal of Range Management 52(5):525-533.*

We determined rates of western juniper (Juniperus occidentalis spp. occidentalis Hook.) density and cover change during the period 1951 to 1994 at 3 adjacent sites with nearly identical elevation, slope, aspect, soils, plant communities, and climate, but different land-use histories. The 3 sites are located in central Oregon at the confluence of the Deschutes and Crooked Rivers. Two of the sites are typical of central Oregon rangelands in that they have a history of anthropogenic disturbance including active fire suppression and domestic livestock grazing. The third site is a relict mesa that is a protected Research Natural Area and has experienced minimal anthropogenic impacts. We used large scale aerial photography to determine cover and density of western juniper in 1951, 1956, 1961, 1972, 1982, and 1994. We found that western juniper density and cover during the last 4 decades increased at all sites, with changes on the relict site similar to those on one of the disturbed sites. We suggest that even though 2 of the traditionally cited causes of western juniper expansion since the late 1800s (altered fire regimes, domestic livestock grazing) may have contributed to expansion on our disturbed sites, these mechanisms can not explain expansion on the near- relict mesa. Further, we examined climatic changes since 1900 in the region and concluded that the data did not fully support a climate-driven mechanism for the expansion. In seeking to explain western juniper expansion on semiarid rangelands, we suggest that all potential causal mechanisms (e.g., fire history, biological inertia, climate, domestic grazing, atmospheric CO2 enrichment) be considered.

KEYWORDS: ATMOSPHERIC CO2 ENRICHMENT, CARBON DIOXIDE, CENTRAL OREGON, GROWTH, OCCIDENTALIS, TRENDS, UNITED-STATES, VEGETATION CHANGE

2249

Soussana, J.F., E. Casella, and P. Loiseau. 1996. Long-term effects of CO2 enrichment and temperature increase on a temperate grass sward .2. Plant nitrogen budgets and root fraction. *Plant and Soil 182(1):101-114.*

Perennial ryegrass swards were grown in large containers on a soil and were exposed during two years to elevated (700 mu L L(-1)) or ambient atmospheric CO2 concentration at outdoor temperature and to a 3 degrees C increase in air temperature in elevated CO2. The nitrogen nutrition of the grass sward was studied at two sub-optimal (160 and 530 kg N ha(-1) y(-1)) and one non-limiting (1000 kg N ha(-1) y(-1)) N fertilizer supplies. At cutting date, elevated CO2 reduced by 25 to 33%, on average, the leaf N concentration per unit mass. Due to an increase in the leaf blade weight per unit area in elevated CO2, this decline did not translate for all cuts in a lower N concentration per unit leaf blade area. With the non-limiting N fertilizer supply, the leaf N concentration (% N) declined with the shoot dry-matter (DM) according to highly significant power models in ambient (% N=4.9 DM(-0.38)) and in elevated (% N=5.3 DM(-0.52)) CO2. The difference between both regressions was significant and indicated a lower critical leaf N concentration in elevated than in ambient CO2 for high, but not for low values of shoot biomass. With the sub-optimal N fertilizer supplies, the nitrogen nutrition index of the grass sward, calculated as the ratio of the actual to the critical leaf N concentration, was significantly lowered in elevated CO2. This indicated a lower inorganic N availability for the grass plants in elevated CO2, which was also apparent from the significant declines in the annual nitrogen yield of the grass sward and in the nitrate leaching during winter. For most cuts, the harvested fraction of the plant dry-matter decreased in elevated CO2 due, on average, to a 45-52% increase in the root phytomass. In the same way, a smaller share of the plant total nitrogen was harvested by cutting, due, on average, to a 25-41% increase in the N content of roots. The annual means of the DM and N harvest indices were highly correlated to the annual means of the nitrogen nutrition index. Changes in the harvest index and in the nitrogen nutrition index between ambient and elevated CO2 were also positively correlated. The possible implication of changes in the soil nitrogen cycle and of a limitation in the shoot growth potential of the grass in elevated. CO2 is discussed.

KEYWORDS: CANOPY, CARBON-DIOXIDE CONCENTRATION, DRY-MATTER, ELEVATED CO2, GROWTH, LEAF, NUTRITION, PERENNIAL RYEGRASS, PHOTOSYNTHESIS, TALL FESCUE

2250

Soussana, J.F., and U.A. Hartwig. 1996. The effects of elevated CO2 on symbiotic N-2 fixation: A link between the carbon and nitrogen cycles in grassland ecosystems. *Plant and Soil 187(2):321-332.*

The response of plants to elevated CO2 is dependent on the availability of nutrients, especially nitrogen. It is generally accepted that an increase in the atmospheric CO2 concentration increases the C:N ratio of plant residues and exudates. This promotes temporary N-immobilization which might, in turn, reduce the availability of soil nitrogen. In addition, both a CO2 stimulated increase in plant growth (thus requiring more nitrogen) and an increased N demand for the decomposition of soil residues with a large C:N will result under elevated CO2 in a larger N-sink of the whole grassland ecosystem. One way to maintain the balance between the C and N cycles in elevated CO2 would be to increase N-import to the grassland ecosystem through symbiotic N-2 fixation. Whether this might happen in the context of temperate ecosystems is discussed, by assessing the following hypothesis: i) symbiotic N-2 fixation in legumes will be enhanced under elevated CO2, ii) this enhancement of N- 2 fixation will result in a larger N-input to the grassland ecosystem, and iii) a larger N input will allow the sequestration of additional carbon, either above or below- ground, into the ecosystem. Data from long-term experiments with model grassland ecosystems, consisting of monocultures or mixtures of perennial ryegrass and white clover, grown under elevated CO2 under free-air or field-like conditions, supports the first two hypothesis, since: i) both the percentage and the amount of fixed N increases in white clover grown under elevated CO2 ii) the contribution of fixed N to the nitrogen nutrition of the mixed grass also increases in elevated CO2. Concerning the third hypothesis? an increased nitrogen input to the grassland ecosystem from N-2 fixation usually promotes shoot growth (above-ground C storage) in elevated CO2. However, the consequences of this larger N input under elevated CO2 on the belowground carbon fluxes are not fully understood. On one hand, the positive effect of elevated CO2 on the quantity of plant residues might be overwhelming and lead to an increased long-term below-ground C storage; on the other hand, the enhancement of the decomposition process by the N-rich legume material might favour carbon turn-over and, hence, limit the storage of below-ground carbon.

KEYWORDS: ACETYLENE-REDUCTION ACTIVITY, ATMOSPHERIC CO2, BIRDSFOOT-TREFOIL, CLOVER TRIFOLIUM-REPENS, HYDROGEN EVOLUTION, LEGUME NODULES, MEDICAGO-SATIVA, NITRATE INHIBITION, ROOT NODULE ACTIVITY, WHITE CLOVER

2251

Sozzi, G.O., G.D. Trinchero, and A.A. Fraschina. 1999. Controlled-atmosphere storage of tomato fruit: low oxygen or elevated carbon dioxide levels alter galactosidase activity and inhibit exogenous ethylene action. *Journal of the Science of Food and Agriculture 79(8):1065-1070.*

The effects of 3% O-2 and 20% CO2, both alone and together with 100 mu g g(-1) C2H4, on ethylene production, chlorophyll degradation, carotenoid biosynthesis and alpha- and beta- galactosidase activity in breaker tomato (Lycopersicon esculentum Mill) fruit were investigated. The low O-2 and high CO2 atmospheres prevented the rise in ethylene production, total carotenoid and lycopene biosynthesis and alpha- and beta- galactosidase activity and slowed down chlorophyll degradation and loss of firmness ($P<0.05$). These suppressive effects were not reversed, or only in part - in the case of chlorophyll breakdown - by addition of 100 mu g g(-1) C2H4 to said controlled atmospheres. After transfer from the various atmospheres to air, flesh firmness decreased and ethylene production, total carotenoids, lycopene and beta-galactosidase II activity increased but these parameters were, in all cases, still significantly different from those of fruit held in air. Keeping tomatoes in controlled atmospheres, even in the presence of ethylene, had marked residual effects. Results suggest an antagonism between elevated CO2/low O-2 and exogenous ethylene which could determine most of the ripening parameter behaviour under controlled-atmosphere storage, though a direct regulatory mechanism by O-2 and/or CO2 should not be discarded. (C) 1999 Society of Chemical Industry.

KEYWORDS: BIOSYNTHESIS, CELL-WALL POLYSACCHARIDES, CELLULASE, DEGRADATION, POLYGALACTURONASE, PROTEIN, RNA, STRESS

2252

Spring, G.M., G.H. Priestman, and J.P. Grime. 1996. A new field technique for elevating carbon dioxide levels in climate change experiments. *Functional Ecology 10(4):541-545.*

1. A compact, low-cost, free-air carbon dioxide enrichment system for use in climate change experiments is described, The system has been used in a small-scale study of the effects of an enriched carbon dioxide atmosphere on the growth and functioning of a natural plant community, 2. The experiment ran for 4 months in summer on a nutrient-poor limestone grassland in Derbyshire, The study examined the separate and combined effects of elevated CO2, temperature and soil nutrient status on the growth of seedlings of obligate mycorrhizal and non- mycorrhizal plant species native to the site. 3. It was demonstrated that the CO2 elevation could be controlled within the limits set for 64% of the time. Significant effects of elevated CO2 on the growth and recruitment of seedlings were found in the presence of added nutrients and elevated temperatures.

KEYWORDS: CO2- ENRICHMENT, GROWTH, LIGHT, NUTRIENTS, PLANTS, RESPONSES

2253

Spunda, V., J. Kalina, M. Cajanek, H. Pavlickova, and M.V. Marek. 1998. Long-term exposure of Norway spruce to elevated CO2 concentration induces changes in photosystem II mimicking an adaptation to increased irradiance. *Journal of Plant Physiology 152(4-5):413-419.*

Fifteen-year-old Norway spruces (Picea abies [L.] Karst.) were grown in open top chambers (OTC) at ambient (A) and elevated (i.e. ambient + 350 mu mol(CO2)mol(-1)) concentrations of CO2 (E) for four growing seasons (1992-1995). During this time period several examples of the depression of photosynthetic activities were observed for E needles. In order to better characterize the nature of this depression the gas exchange and fluorescence parameters were analyzed on current year needles during the last season (July 1995). The photon flux density response curves of CO2 uptake (P-N) revealed a significantly reduced stimulation of P-N for E needles as compared with short-term exposure to doubled CO2. Moreover, the sudden exposure of E shoots to 350 mu mol(CO2)mol(-1) at saturating irradiance revealed a depression of both P-Nmax (by 20 %) and quantum yield of PS II (by 32 %) compared with A shoots measured at 350 mu mol(CO2)mol(-1). The data supporting the diminished light harvesting system of photosystem II (PS II) in E shoots compared with A shoots were obtained from pigment analysis, low temperature fluorescence spectra and Chl a fluorescence induction kinetics. The relative proportion of inactive reaction centres of PS II determined from F-pl of the fluorescence induction was 20 % higher for E needles. These changes found for E needles mimicked an adaptation of PS II to increased irradiance compared with A needles. As the irradiance exposure was the same for the examined needles from both E and A spruces we suggest that these changes reported for E needles resulted from the feed-back limitation of photochemical reactions due to suppressed electron transport through the plastoquinone pool.

KEYWORDS: ACCLIMATION, ATMOSPHERIC CO2, CARBON DIOXIDE, CHLOROPHYLL FLUORESCENCE, GAS-EXCHANGE, GROWTH, LEAVES, PHOTOINHIBITION, PHOTOSYNTHESIS, TOMATO PLANTS

2254

Sritharan, R., H. Caspari, and F. Lenz. 1992. Influence of co2 enrichment and phosphorus supply on growth, carbohydrates and nitrate utilization of kohlrabi plants. *Gartenbauwissenschaft 57(5):246-251.*

Kohlrabi (Brassica oleracea var. gongylodes (L.) cv. Express Forcer) plants were grown in sand with adequate nutrient supply. From two weeks after germination until harvest they were treated with two levels of phosphorus supply (1.0 or 0.005 mM P). Four weeks after introducing the P supply regimes the plants were exposed to either a low (300 muL CO2 L-1) or high (900 muL CO2 L-1) CO2 concentration in growth chambers for three weeks. At elevated CO2 concentration plants with 1.0 mM phosphorus produced a larger leaf area and dry matter than those grown at low CO2. At reduced P supply CO2 enrichment promoted leaf senescence and did not increase growth and dry matter. Phosphorus deficiency resulted in increased accumulation of starch in leaves, tuber, and roots and reduced NO3-N concentrations in all plant parts. The CO2 enrichment reduced N and NO3 concentration and increased nitrate utilization efficiency at both P levels. Phosphorus deficiency decreased nitrogen, potassium, calcium, and magnesium concentrations in leaves particularly at high CO2.

KEYWORDS: ACCUMULATION, CARBON DIOXIDE, EXCHANGE, LEAVES, NITROGEN, NUTRITION, PHOSPHATE STATUS, PHOTOSYNTHESIS, REDUCTASE-ACTIVITY, STARCH

2255

Sritharan, R., and F. Lenz. 1992. Effects of carbon-dioxide enrichment and nitrogen supply on kohlrabi (brassica-oleracea var gongylodes L) .1. Water-use, gas-exchange, and carbohydrate partitioning. *Gartenbauwissenschaft 57(3):138-145.*

Six weeks old kohlrabi plants (Brassica oleracea var, gongylodes [L.] cv.

Express Forcer) were grown in growth chambers for three weeks at two levels of CO2 concentration (300-mu-l CO2 l-1-low or 900-mu-l CO2 l-1-high) and three levels of N-nutritional regimes (0.1, 1.0 or 6.0 mM nitrate supply). Carbon dioxide enrichment significantly increased total water uptake of plants at all N supply levels. Water use efficiency, photosynthesis and stomatal conductance were increased by high CO2 only at 1.0 and 6.0 mM supply and reduced at the lowest N level. Photosynthetic efficiency (mu-Mol CO2 fixed m-2 s-1 per mu-l intercellular CO2 l-1) was reduced by both low N supply and CO2 enrichment. Intercellular CO2 concentration was not affected by N deficiency at both CO2 levels. Low NO3 had a lesser effect on photosynthesis than on leaf area growth; photosynthetic rates of mature leaves at both CO2 levels were lowered by about 30 % as compared to the respective controls, after seven weeks of reduction in NO3 supply. In leaves lowest NO3 treatment increased starch and sucrose and in roots starch glucose, fructose, and sucrose and in tuber starch concentrations. Photosynthetic reduction at low N supply showed a significant correlation with leaf starch concentration at both CO2 levels indicating that the inhibition is a result of feed back inhibition. Carbohydrate partitioning within the plant organs were predominantly governed by N supply levels than CO2 treatments.

KEYWORDS: ACCUMULATION, CO2, CONDUCTANCE, COTTON, LEAVES, PHOTOSYNTHESIS, STRESS, TRANSPIRATION

2256
Staddon, P.L. 1998. Insights into mycorrhizal colonisation at elevated CO2: a simple carbon partitioning model. *Plant and Soil 205(2):171-180.*

A simulation model was used to investigate the effect of an increased rate of plant photosynthesis at enhanced atmospheric CO2 concentration on a non-leguminous plant-mycorrhizal fungus association. The model allowed the user to modify carbon allocation patterns at three levels: (1) within the plant (shoot-root), (2) between the plant and the mycorrhizal fungus and (3) within the mycorrhizal fungus (intraradical- extraradical structures). Belowground (root and fungus) carbon losses via respiration (and turnover) could also be manipulated. The specific objectives were to investigate the dynamic nature of the potential effects of elevated CO2 on mycorrhizal colonisation and to elucidate some of the various mechanisms by which these effects may be negated. Many of the simulations showed that time (i.e. plant age) had a more significant effect on the observed stimulation of mycorrhizal colonisation by elevated CO2 than changes in carbon allocation patterns or belowground carbon losses. There were two main mechanisms which negated a stimulatory effect of elevated CO2 on internal mycorrhizal colonisation: an increased mycorrhizal carbon allocation to the external hyphal network and an increased rate of mycorrhizal respiration. The results are discussed in relation to real experiments. The need for studies consisting of multiple harvests is emphasised, as is the use of allometric analysis. Implications at the ecosystem level are discussed and key areas for future research are presented.

KEYWORDS: ATMOSPHERIC CO2, BOUTELOUA-GRACILIS, CLIMATE CHANGE, DIOXIDE, GROWTH, INFECTION UNITS, PLANTS, RESPONSES, ROOTS, TRIFOLIUM-SUBTERRANEUM L

2257
Staddon, P.L., and A.H. Fitter. 1998. Does elevated atmospheric carbon dioxide affect arbuscular mycorrhizas? *Trends in Ecology and Evolution 13(11):455-458.*

It is well established that an increase in the concentration of atmospheric CO2 stimulates plant growth. Recently, many researchers have concluded that elevated CO2 concentrations also stimulate mycorrhizal colonization. However, new evidence suggests that the observed CO2 effects on arbuscular mycorrhizal fungi are indirect and are a result of faster plant growth at higher CO2 concentrations. Potential changes to species assemblages of mycorrhizal fungi could affect soil carbon storage and, consequently, the feedback effects of terrestrial soil-vegetation systems on global environmental change.

KEYWORDS: BOUTELOUA-GRACILIS, CO2- ENRICHMENT, COLONIZATION, GROWTH, INFECTION, QUERCUS-ALBA, RESPONSES, ROOT, SEEDLINGS, SOIL

2258
Staddon, P.L., A.H. Fitter, and J.D. Graves. 1999. Effect of elevated atmospheric CO2 on mycorrhizal colonization, external mycorrhizal hyphal production and phosphorus inflow in Plantago lanceolata and Trifolium repens in association with the arbuscular mycorrhizal fungus Glomus mosseae. *Global Change Biology 5(3):347-358.*

Plantago lanceolata and Trifolium repens were grown under ambient (400 mu mol. mol(-1)) and elevated (650 mu mol mol(-1)) atmospheric CO2 conditions. Plants were inoculated with the arbuscular mycorrhizal fungus Glomus mosseae and given a phosphorus supply in the form of bonemeal. Six sequential harvests were taken in order to determine whether the effect of elevated CO2 on internal mycorrhizal colonization and external hyphal production was independent of the stimulatory effect of elevated CO2 on plant growth. At a given time, elevated CO2 increased the percentage of root length colonized (RLC), the total length of colonized root and the external mycorrhizal hyphal (EMH) density and decreased the ratio of EMH to total length of colonized root. When plant size was taken into account, the CO2 effect on RLC and total length of colonized roof was greatly reduced land only apparent for early harvests in T. repens) and the effects on the EMH parameters disappeared. Root tissue P concentration was unchanged at elevated CO2, but there was a decrease in shoot P at the later harvests. There was no direct effect of elevated CO2 on P inflow for the earlier period (< 50 d) of the experiment. However, over the last period, there was a significant negative effect of elevated CO2 on P inflow for both species, independent of plant size. It is concluded that elevated CO2 had no direct effect on mycorrhizal colonization or external hyphal production, and that any observed effects on a time basis were due to faster growing plants at elevated CO2. However, for older plants, elevated CO2 had a direct negative effect on P inflow This decrease in P inflow coincides with the observed decrease in shoot P concentration. This is discussed in terms of downregulation of photosynthesis often seen in elevated CO2 grown plants, and the potential for mycorrhizas (via external hyphal turnover to alleviate the phenomenon. The direction for future research is highlighted, especially in relation to carbon flow to and storage in the soil.

KEYWORDS: BOUTELOUA-GRACILIS, CLIMATE CHANGE, ENRICHMENT, GLOBAL CARBON-CYCLE, GROWTH, QUERCUS-ALBA, ROOT, SINK ACTIVITY, SOIL, SUBTERRANEUM L

2259
Staddon, P.L., A.H. Fitter, and D. Robinson. 1999. Effects of mycorrhizal colonization and elevated atmospheric carbon dioxide on carbon fixation and below-ground carbon partitioning in Plantago lanceolata. *Journal of Experimental Botany 50(335):853-860.*

Plantago lanceolata with or without the mycorrhizal fungus Glomus mosseae were grown over a 100 d period under ambient (380 +/- 50 mu mol mol(-1)) and elevated (600 +/- 150 mu mol mol(-1)) atmospheric CO2 conditions. To achieve similar growth, non-mycorrhizal plants received phosphorus in solution whereas mycorrhizal plants were supplied with bonemeal. Measures of plant growth, photosynthesis and carbon input to the soil were obtained, Elevated CO2 stimulated plant growth to the same extent in mycorrhizal and non-mycorrhizal plants,

but had no effect on the partitioning of carbon between shoots and roots or on shoot tissue phosphorus concentration. Mycorrhizal colonization was low, but unaffected by CO2 treatment. Net photosynthesis was stimulated both by mycorrhizal colonization and elevated CO2, and there was a more than additive effect of the two treatments on net photosynthesis. Colonization by mycorrhizal fungi inhibited acclimation, in terms of net carbon assimilation, of plants to elevated CO2. C-13 natural abundance techniques were used to measure carbon input into the soil, although the results were not conclusive. Direct measurements of below-ground root biomass showed that elevated CO2 did stimulate carbon flow below-ground and this was higher in mycorrhizal than non-mycorrhizal plants. For the four treatment combinations, the observed relative differences in amount of below-ground carbon were compared with those expected from the differences in net photosynthesis. A considerable amount of the extra carbon fixed both as a result of mycorrhizal colonization and growth in elevated CO2 did not reveal itself as increased plant biomass, As there was no evidence for a substantial increase in soil organic matter, most of this extra carbon must have been respired by the mycorrhizal fungus and the roots or by the the plants as dark-respiration. The need for detailed studies in this area is emphasized.

KEYWORDS: CO2- ENRICHMENT, GLOMUS-MOSSEAE, GROWTH, NATURAL ECOSYSTEMS, PHOTOSYNTHESIS, RESPONSES, SOIL, SOURCE-SINK RELATIONS, TRIFOLIUM- REPENS, USE EFFICIENCY

2260

Staddon, P.L., J.D. Graves, and A.H. Fitter. 1998. Effect of enhanced atmospheric CO2 on mycorrhizal colonization by Glomus mosseae in Plantago lanceolata and Trifolium repens. *New Phytologist 139(3):571-580.*

Plantage lanceolata L. and Trifolium repens L. were grown for 16 wk in ambient (360 mu mol mol(-1)) and elevated (610 mu mol mol(-1)) atmospheric CO2. Plants were inoculated with the arbuscular mycorrhizal (AM) fungus Glomus mosseae (Nicol. & Gerd.) Gerdemann & Trappe and given a phosphorus supply in the form of bonemeal, which would not be immediately available to the plants. Seven sequential harvests were taken to determine whether the effect of elevated CO2 on mycorrhizal colonization was independent of the effect of CO2 on plant growth. Plant growth analysis showed that both species grew faster in elevated CO2 and that P. lanceolata had increased carbon allocation towards the roots. Elevated CO, did not affect the percentage of root length colonized (RLC); although total colonized root length was greater, when plant size was taken into account this effect disappeared. This finding was also true for root length colonized by arbuscules. No CO2 effect was found on hyphal density (colonization intensity) in roots. The P content of plants was increased at elevated CO2, although both shoot and root tissue P concentration were unchanged. This was again as a result of bigger plants at elevated CO2. Phosphorus inflow was unaffected by CO2 concentrations. It is concluded that there is no direct permanent effect of elevated CO2, on mycorrhizal functioning, as internal mycorrhizal development and the mycorrhizal P uptake mechanism are unaffected. The importance of sequential harvests in experiments is discussed. The direction for future research is highlighted, especially in relation to C storage in the soil.

KEYWORDS: BOUTELOUA-GRACILIS, CLIMATE CHANGE, ELEVATED CO2, ENRICHMENT, GLOBAL CARBON-CYCLE, GROWTH, QUERCUS-ALBA, RESPONSES, ROOTS, SINK

2261

Staddon, P.L., J.D. Graves, and A.H. Fitter. 1999. Effect of enhanced atmospheric CO2 on mycorrhizal colonization and phosphorus inflow in 10 herbaceous species of contrasting growth strategies. *Functional Ecology 13(2):190-199.*

1, Ten herbaceous species were grown over a 4-month period under ambient (360 mu mol mol(-1)) and elevated (610 mu mol mol(-1)) atmospheric CO2 conditions. Plants were inoculated with the arbuscular mycorrhizal (AM) fungus Glomus mosseae and given a phosphorus (P) supply which was not immediately available to the plants. 2. Multiple harvests were taken in order to determine whether the effect of elevated CO2 on mycorrhizal colonization and phosphorus inflow was independent of its effect on plant growth. 3, All species grew faster under elevated CO2 and carbon partitioning was altered, generally in favour of the shoots. All species responded similarly to elevated CO2. 4. Elevated CO2 did not affect the percentage of root length colonized by AM fungi, but the total amount of colonized root length was increased, because the plants were bigger. 5. Elevated CO2 increased total P content, but had little or no effect on P concentration. At a given age, P inflow was stimulated by elevated CO2, but when root length was taken into account the CO2 effect disappeared. 6. In these host species there is no evidence for a direct effect of elevated CO2 on mycorrhizal functioning, because both internal mycorrhizal colonization and P inflow are unaffected. 7. Future research should concentrate on the potential for carbon flow to the soil via the external mycelial network.

KEYWORDS: BOUTELOUA-GRACILIS, CLIMATE CHANGE, ELEVATED CARBON-DIOXIDE, ENRICHMENT, NUTRITION, PLANTAGO-LANCEOLATA, QUERCUS-ALBA, RESPONSES, ROOT, TRIFOLIUM- REPENS

2262

Stange, G. 1997. Effects of changes in atmospheric carbon dioxide on the location of hosts by the moth, Cactoblastis cactorum. *Oecologia 110(4):539-545.*

Sensory organs that detect CO2 are common in herbivorous moths and butterflies, but their function has been unclear until now. As the CO2 gradients in the vicinity of a host plant depend on its physiological condition, CO2 could provide a sensory cue for the suitability of the plant as a larval food source. This study investigated whether changing the atmospheric CO2 concentration affected oviposition by Cactoblastis cactorum on its host, the cactus Opuntia stricta. On host plants exposed to rapid fluctuations in CO2 concentration, the frequency of oviposition was reduced by a factor of 3.2 compared to the control. As the fluctuations mask the much smaller CO2 signals generated by the plants, this suggests that those signals constitute an important component of the host identification process. On host plants exposed to a constant background of doubled CO2, oviposition was also reduced, by a factor of 1.8. An increased background reduces host signal detectability, partially as a consequence of a general principle of sensory physiology (Weber-Fechner's law), and partially due to other factors specific to CO2-receptor neurons.

KEYWORDS: AUSTRALIA, BIOLOGICAL-CONTROL, ELEVATED CO2, LEPIDOPTERA, NOCTUIDAE, OPEN-TOP CHAMBERS, OPUNTIA-STRICTA, PIT ORGAN, RECEPTORS, SELECTION

2263

Stanghellini, C., and J.A. Bunce. 1993. Response of photosynthesis and conductance to light, co2, temperature and humidity in tomato plants acclimated to ambient and elevated co2. *Photosynthetica 29(4):487-497.*

In tomato (Lycopersicon esculentum L.) plants, net carbon dioxide exchange rate (P(N)) response curves to both irradiance (I) and short-term [CO2] were similar for plants grown at both 350 and 700 cm3(CO2) m-3. However, water vapor conductance (gH2O) of plants grown at high [CO2] was less sensitive to short term [CO2] variations,

when measured at low vapor pressure difference, and was larger than the conductance of "ambient [CO2]" plants when both were exposed to high [CO2]. P(N) and g(H2O) under high I increased with temperature over the range 18 to 32-degrees-C. P(N) of plants grown in both [CO2] treatments increased at most about 25 % from 350 to 700 cm3 m-3 at 18 and 25-degrees-C, and decreased when exposed to 1000 cm3 m-3 at these temperatures. Thus increasing atmospheric [CO2] might not increase P(N) by as much as expected and water use of crops might not decrease.

KEYWORDS: C-3, CARBON DIOXIDE, CARBOXYLASE, FIELD-GROWN TOMATO, HIGH ATMOSPHERIC CO2, INHIBITION, O2, SENSITIVITY, STOMATAL CLOSURE, TERM

2264

Steffen, W.L., W. Cramer, M. Plochl, and H. Bugmann. 1996. Global vegetation models: Incorporating transient changes to structure and composition. *Journal of Vegetation Science 7(3):321-328.*

We describe an approach for developing a Dynamic Global Vegetation Model (DGVM) that accounts for transient changes in vegetation distribution over a decadal time scale. The DGVM structure is based on a linkage between an equilibrium global vegetation model and smaller scale ecosystem dynamics modules that simulate the rate of vegetation change. Vegetation change is classified into four basic types, based largely on the projected change in above-ground biomass of the vegetation. These four types of change are: (1) dieback of forest, shrubland or grassland; (2) successional replacement within forest, shrubland or grassland; (3) invasion of forest, shrubland or grassland; (4) change in tree/grass ratio. We then propose an approach in which the appropriate ecosystem dynamics module for each type of change is applied and the grid cells of the global model updated accordingly. An approach for accounting for fire, as an example of a disturbance which may strongly influence the rate and spatial pattern of forest dieback, is incorporated. We also discuss data needs for the development, calibration and validation of the model.

KEYWORDS: ATMOSPHERE, CO2, CO2-INDUCED CLIMATE CHANGE, DEFORESTATION, ECOSYSTEMS, FORESTS, IMPACT, SIMULATION-MODEL, SOIL, TERRESTRIAL CARBON STORAGE

2265

Steffen, W.L., and J.S.I. Ingram. 1995. Global change and terrestrial ecosystems: An initial integration. *Journal of Biogeography 22(2-3):165-174.*

We present a framework for integrating GCTE's research programme based on three interacting axes-time, space and applicability. We use the contributed papers from the First GCTE Science Conference to undertake an initial integration of GCTE-type research using this three-axis structure. We assess where progress is being made, where progress is likely to be made in the near future, and where critical gaps exist which require a major effort to eliminate. Elevated CO2 research is one of the most mature areas within GCTE, and provides scope for initial integration along all three axes. Soils, being key to the functioning of all terrestrial ecosystems, provide another excellent opportunity to integrate research along all three axes. A major obstacle to further integration is our lack of understanding of landscape-scale processes, particularly disturbances, and our ability to simulate global change impacts on them. GCTE's Focus 2, Change in Ecosystem Structure, is perhaps best placed to attack many of the gaps that prevent this further integration along space and time scales, and is now entering a rapid development phase; the other Foci also have a major role to play. Integration specifically along the applicability axis is being developed in some areas but requires an enhanced effort to achieve its potential to increase scientific efficiency and effectiveness. The emerging field of global ecology, i.e. ecology at very large space and time scales, is progressing rapidly on the basis of linkages to more traditional ecological research at smaller scales, but requires further interaction with work along the applicability axis.

2266

Steinger, T., C. Lavigne, A. Birrer, K. Groppe, and B. Schmid. 1997. Genetic variation in response to elevated CO2 in three grassland perennials - a field experiment with two competition regimes. *Acta Oecologica-International Journal of Ecology 18(3):263-268.*

Intraspecific Variation in the response to increased concentrations of atmospheric CO2 was investigated in three plant species (Bromus erectus, Prunella vulgaris, P. grandiflora) in a calcareous grass land. Genotypes of each species were grown both in multispecies communities and under reduced competition pressure in tubes buried in the soil. Plant growth was reduced in the artificial communities but no significant effect of CO2 was observed on any of the measured traits. Significant genotype by-CO2 interactions were found in two species when plants were grown under reduced competition in the tubes. No genotype-by-CO2 interactions were found for the same genotypes grown in the multispecies communities indicating that genetic variation was swamped by large environmental variation. Furthermore, no correlations were observed between CO2 responses of identical genotypes grown individually in tubes and in multispecies communities. This result cautions about the ability to predict CO2-induced evolutionary changes from data of individually-grown plants.

KEYWORDS: ENVIRONMENTS, PLANTS

2267

Stekiel, T.A., W.J. Stekiel, M. Tominaga, A. Stadnicka, Z.J. Bosnjak, and J.P. Kampine. 1996. Effect of halothane and isoflurane on in situ diameter responses of small mesenteric veins to acute graded hypercapnia. *Anesthesia and Analgesia 82(2):349-357.*

The purpose of the present study was to quantify the inhibitory effect of inhaled halothane and isoflurane on acute hypercapnia-induced responses of capacitance-regulating veins and related cardiovascular variables in response to sequential 40-s periods of 5%, 10%, 15%, and 20% inspired CO2 (FICO2). Measurements were made in normoxic alpha-chloralose- anesthetized rabbits before, during, and after either 0.75 minimum alveolar anesthetic concentration inhaled halothane or isoflurane. The graded hypercapnia caused graded venoconstriction and bradycardia but minimal presser responses. Hypercapnia-induced venoconstriction was blocked by prior local superfusion of the exposed veins with 3 x 10(-6) M tetrodotoxin. Both the hypercapnia-induced venoconstriction and bradycardia responses were significantly attenuated by halothane or isoflurane and did not fully recover af ter removal of the anesthetics from the circulation. Both anesthetics produced a significant baseline (i.e., prehypercapnia) hypotension and a tendency toward a resultant tachycardia. The baseline hypotension did not recover completely after elimination of the anesthetic. Neither anesthetic altered baseline vein diameter. These results agree with previous studies demonstrating that hypercapnic acidosis :produces mesenteric venoconstriction by elevating excitatory sympathetic efferent neural input via activation of peripheral and central chemoreceptors and that bradycardia results from activation of compensatory baroreflexes. The neural components of these reflexes are possible primary sites for attenuation of these cardiovascular responses by halothane and isoflurane.

KEYWORDS: ANESTHESIA, ANESTHETIZED DOGS, BARORECEPTOR, CARBON DIOXIDE, CIRCULATION, HYPOXIC HYPERCAPNIA, RABBITS, REFLEX CONTROL, SYMPATHETIC-NERVE ACTIVITY, VASCULAR CAPACITANCE

2268
Sternberg, M., V.K. Brown, G.J. Masters, and I.P. Clarke. 1999. Plant community dynamics in a calcareous grassland under climate change manipulations. *Plant Ecology 143(1):29-37.*

This study investigates the effects of field manipulations of local climate to determine the potential impact of climate change on plant community dynamics in a calcareous grassland. The experimental site is located in a grassland at the Wytham estate, Oxfordshire, UK. The one hectare study area is within a 10 ha abandoned arable field on Jurassic corallian limestone. Two climate change scenarios were used: warmer winters with increased summer rainfall and warmer winters with summer drought. Plant cover and species richness were significantly increased in plots receiving supplemented summer rainfall, while the amount of litter was significantly reduced. Litter formation was significantly increased by winter warming and drought. The responses of the plant community to the climate manipulations were related to the life-history attributes of the dominant species. Seedling recruitment was limited by microsite availability, which also varied in the different climate manipulations. The results are discussed in terms of successional dynamics. They suggest that warmer winters may delay succession, as gap formation in the sward will provide sites for colonisation of annuals, thereby enabling their persistence in the sward. Under wetter conditions during summer, perennial grasses tend to close the sward, thereby inhibiting the establishment of later successional species.

KEYWORDS: ELEVATED CO2, GROWTH, INSECT HERBIVORE INTERACTIONS, LITTER DECOMPOSITION, MECHANISMS, NITROGEN, RESPONSES, SEEDLING ESTABLISHMENT, TEMPERATURE, TUNDRA

2269
Stewart, J.D., and J. Hoddinott. 1993. Photosynthetic acclimation to elevated atmospheric carbon- dioxide and uv irradiation in pinus-banksiana. *Physiologia Plantarum 88(3):493-500.*

Pinus banksiana seedlings were grown for 9 months in enclosures in greenhouses at CO2 concentrations of 350 or 750 mumol mol-1 with either low (0.005 to 0.3 W M-2) or high (0.25 to 0.90 W M- 2) ultraviolet-B (UV-B) irradiances. Total seedling dry weight decreased with high UV treatment but was unaffected by CO2 enrichment. High UV treatment also shifted biomass partitioning in favor of leaf production. Both CO2 and UV treatments decreased the dark respiration rate and light compensation point. High UV light inhibited photosynthesis at 350 but not at 750 mumol mol-1 CO2 due to a UV induced increase in ribulose- 1,5-bisphosphate carboxylase/oxygenase efficiency and ribulose- 1,5-bisphosphate regeneration. Stomatal density was increased by high UV irradiance but was unchanged by CO2 enrichment.

KEYWORDS: ABSCISIC- ACID, C-3, CO2, GAS-EXCHANGE, GROWTH, LEAVES, PLANTS, SEEDLINGS, STOMATAL CLOSURE, ULTRAVIOLET-B RADIATION

2270
Stewart, J., and C. Potvin. 1996. Effects of elevated CO2 on an artificial grassland community: Competition, invasion and neighbourhood growth. *Functional Ecology 10(2):157-166.*

1. We analysed the effect of CO2 enrichment on plant-plant interactions in an artificial community dominated by Trifolium repens and Poa pratensis. Plants were enriched either in open- tops or growth chambers. 2. Our main hypotheses were supported, i.e. elevated CO2 increased the strength and number of plant- plant interactions and Trifolium benefited more than Poa from a high CO2 concentration. However, responses differed depending on whether plants were enriched in open-top or in growth chambers. These differences are discussed regarding possible density dependence. 3. This study emphasizes the importance of invasions in the dynamics of our artificial community. Invasiveness was best predicted by traits pertaining to space acquisition. 4. To provide insights into evolutionary processes, phenotypic plasticity and genetic correlation of individual traits were analysed across environments. Our results suggest that little opportunity had occurred for adaptive plasticity to evolve for most characters.

KEYWORDS: ABILITY, EVOLUTIONARY-THEORY, PLANTS

2271
Stiling, P., A.M. Rossi, B. Hungate, P. Dijkstra, C.R. Hinkle, W.M. Knott, and B. Drake. 1999. Decreased leaf-miner abundance in elevated CO2: Reduced leaf quality and increased parasitoid attack. *Ecological Applications 9(1):240-244.*

Most studies on the effects of elevated CO2 have focused on the effects on plant growth and ecosystem processes. Fewer studies have examined the effects of elevated CO2 on herbivory, and of these, most have examined feeding rates in laboratory conditions. Our study takes advantage of an open-top CO2 fertilization study in a Florida scrub-oak community to examine the effects of elevated CO2 on herbivore densities, herbivore feedings rates, and levels of attack of herbivores by natural enemies. Higher atmospheric CO2 concentration reduced plant foliar nitrogen concentrations, decreased abundance of leaf- mining insect herbivores, increased per capita leaf consumption by leafminers, and increased leaf miner mortality. As suggested by other authors, reduced foliar quality contributed to the increase in herbivore mortality, but only partly. The major factor increasing mortality was higher attack rate by parasitoids. Thus increasing CO2 concentrations may reduce the survivorship of insect herbivores directly, by reducing plant quality, but also indirectly, by changing herbivore feeding and eliciting greater top-down pressure from natural enemies.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, DECIDUOUS TREES, DENSITY, INSECT HERBIVORE INTERACTIONS, LEPIDOPTERA, PERFORMANCE, PHYTOCHEMISTRY, PLANTS, POPULATION

2272
Stirling, C.M., P.A. Davey, T.G. Williams, and S.P. Long. 1997. Acclimation of photosynthesis to elevated CO2 and temperature in five British native species of contrasting functional type. *Global Change Biology 3(3):237-246.*

Acclimation of photosynthesis to growth at elevated CO2 concentration varies markedly between species. Species functionally classified as stress-tolerators (S) and ruderals (R), are thought to be incapable, or the least capable, of responding positively in terms of growth to elevated [CO2]. Is this pattern of response also apparent in leaf photosynthesis of wild S- and R-strategists? Acclimatory loss of a photosynthetic and growth response to elevated [CO2] is assumed to reflect limitation on capacity to utilize additional photosynthate. The doubling of pre-industrial global [CO2] is expected to coincide with a 3 degrees C increase in mean temperature which could stimulate growth; will photosynthetic capacity at elevated [CO2] be greater when the concurrent temperature increase is simulated? Five species from natural grassland of NW Europe and of contrasting ecological strategy were grown in hemispherical greenhouses, environmentally controlled to track the external microclimate. Within a replicated design, plants were grown at (i) current ambient [CO2] and temperature, (ii) elevated [CO2] (ambient + 340 mu mol mol(-1)) and ambient temperature, (iii) ambient [CO2] and elevated temperature (ambient + 3 degrees C), or (iv) elevated [CO2] and elevated temperature. After 75-104 days, the CO2

response of light-saturated rates of photosynthesis (A(sat)) was analysed in controlled-environment cuvettes in a field laboratory. There was no acclimatory loss of photosynthetic capacity with growth in elevated [CO2] or elevated temperature over this period in Poa alpina (S), Bellis perennis (R) or Plantago lanceolata (mixed C-S-R strategist), and a significant ($P < 0.05$) increase in capacity in Helianthemum nummularium (S) and Poa annua (R). Photosynthetic rates of leaves grown and measured in elevated [CO2] were therefore significantly higher than rates for leaves grown and measured in ambient [CO2], for all species. With the exception of Poa alpina, stomatal conductance and stomatal limitation on A(sat) showed no acclimatory response to growth in elevated [CO2]. Carboxylation efficiency, determined from the initial slope of the response of A(sat) to intercellular CO2 concentration was significantly increased by elevated [CO2] and elevated temperature in H. nummularium, implying a possible increase in in vivo RubisCO activity. Increased carboxylation efficiency of this species was also reflected by an increase in the CO2- and light- saturated rates of photosynthesis, indicating an increased capacity for regeneration of the primary CO2 acceptor in photosynthesis. The results show that R-strategists and slow- growing S-strategists, are inherently capable of large increases in leaf photosynthetic capacity with growth in elevated [CO2] in contrast to expectations from growth studies. With the exception of P. annua, where there was a significant negative interaction between CO2 and temperature, concurrent increase in growth temperature had little effect on this pattern of response.

KEYWORDS: ASSIMILATION, ATMOSPHERIC CO2, CARBON DIOXIDE, ENRICHMENT, EXPOSURE, GAS-EXCHANGE, GROWTH, PARTIAL-PRESSURE, PLANTS, RESPONSES

2273

Stirling, C.M., M. Heddell-Cowie, M.L. Jones, T.W. Ashenden, and T.H. Sparks. 1998. Effects of elevated CO2 and temperature on growth and allometry of five native fast-growing annual species. *New Phytologist 140(2):343-354.*

Whereas much is known of the short-term growth response to elevated atmospheric CO2 concentrations, [CO2](elev), there is relatively little information on how the response of native species is modified by temperature, despite the fact that an increase in global mean temperature is expected to accompany the rise in [CO2]. In this study, five functionally related annual native species were exposed to different combinations of ambient and elevated [CO2] and temperatures in order to assess their response in terms of growth and allometry. Fast-growing annuals were selected for the study because their growth responses could be assessed over a major portion of the plant's life cycle and in as short a period as 8 wk. Plants were grown in eight hemi-spherical glasshouses, programmed to track outside ambient conditions and provide a replicated experimental design. Treatments comprised (i) current ambient [CO2] and temperature, (ii) elevated [CO2] (ambient + 34 kPa), and ambient temperature (iii) ambient [CO2] and elevated temperature (ambient + 3 degrees C) and (iv) elevated [CO2] and elevated temperature (T degrees C-elev). All five species responded positively to [CO2](elev), although the response was statistically significant for only one, Poa annua L. Averaged over all five species, [CO2](elev) increased total plant biomass by 25 % ($P = 0.005$) at 56 d, reflecting a proportionally greater increase in leaf and stem mass relative to root weight. Elevated [CO2] had no effect on leaf area, either at the individual species level or overall. Elevated T degrees C, by contrast, had little effect on shoot growth but increased root mass on average by 43 % and leaf area by 22 %. Few interactions between elevated [CO2] and T degrees C were observed, with the CO2 response generally greater at elevated than ambient T degrees C. Both [CO2](elev) and T degrees C-elev resulted in a transient increase in relative growth rate, (RGR), during the first 14 d exposure and a 3 degrees C increase in temperature had no effect on the duration of the response. CO2 stimulation of growth operated through a sustained increase in net assimilation rate. (NAR), although the potential benefit to RGR was offset by a concurrent decline in leaf area ratio (LAR), as a result Of a decrease in leaf area per unit leaf mass (SLA). The response to T degrees C-elev was generally opposite of that to [CO2](elev). For example, T degrees C-elev increased LAR through an increase in SLA and this, rather than any effect on NAR, was the major factor responsible for the stimulation of RGR. Allometric analysis of CO2 effects revealed that changes in allocation observed at individual harvests were due solely to changes associated with plant size. Elevated T degrees C, by contrast, had a direct effect on allocation patterns to leaves, with an increase in leaf area expansion relative to whole plant mass during the initial stages of growth and subsequent increased allocation of biomass away from leaves to other regions of the plant. No change in the allometric relation between roots and shoots were observed at either elevated [CO2] or T degrees C. We conclude, therefore, that allocation of biomass and morphological characteristics such as SLA, are relatively insensitive to [CO2], at least when analysed at the whole-plant level, and where changes have been observed, these are the product of comparing plants of the same age but different size.

KEYWORDS: ALLOCATION, CARBON DIOXIDE, ENRICHMENT, GRASSES, PHOTOSYNTHESIS, PLANTAGO-MAJOR, RESPIRATION, RESPONSES, SINK

2274

Stitt, M. 1991. Rising CO2 levels and their potential significance for carbon flow in photosynthetic cells. *Plant, Cell and Environment 14(8):741-762.*

In the first part of this review, I discuss how we can predict the direct short-term effect of enhanced CO2 on photosynthetic rate in C3 terrestrial plants. To do this, I consider: (1) to what extent enhanced CO2 Will stimulate or relieve demand on partial processes like carboxylation, light harvesting and electron transport, the Calvin cycle, and end-product synthesis; and (2) the extent to which these various processes actually control the rate of photosynthesis. I conclude that control is usually shared between Rubisco (which responds sensitively to CO2) and other components (which respond less sensitively), and that photosynthesis will be stimulated by 25- 75% when the CO2 concentration is doubled from 35 to 70 Pa. This is in good agreement with the published responses. In the next part of the review, I discuss the evidence that most plants undergo a gradual inhibition of photosynthesis during acclimation to enhanced CO2. I argue that this is related to an inadequate demand for carbohydrate in the remainder of the plant. Differences in the long-term response to CO2 may be explained by differences in the sink-source status of plants. depending upon the species, the developmental stage, and the developmental conditions. In the third part of the review, I consider the biochemical mechanisms which are involved in 'sink' regulation of photosynthesis. Accumulating carbohydrate could lead to a direct inhibition of photosynthesis, involving mechanical damage by large starch grains or Pi-limitation due to inhibition of sucrose synthesis. I argue that Pi is important in the short-term regulation of partitioning to sucrose and starch, but that its contribution to 'sink' regulation has not yet been conclusively demonstrated. Indirect or 'adaptive' regulation of photosynthesis is probably more important, involving decreases in amounts of key photosynthetic enzymes, including Rubisco. This decreases the rate of photosynthesis, and potentially would allow resources (e.g. amino acids) to be remobilized from the leaves and reinvested in sink growth to readjust the sink-source balance. In the final part of the review, I argue that similar changes of Rubisco and, possibly, other proteins are probably also involved during acclimation to high CO2.

KEYWORDS: CALVIN CYCLE ENZYMES, DRY-MATTER PRODUCTION, FLUX-CONTROL COEFFICIENTS, HIGH ATMOSPHERIC CO2, LONG-TERM EXPOSURE, PHASEOLUS-VULGARIS L, RIBULOSE BISPHOSPHATE CARBOXYLASE,

ROOTED SOYBEAN LEAVES, SOURCE SINK BALANCE, SUCROSE PHOSPHATE SYNTHASE

2275

Stitt, M., and A. Krapp. 1999. The interaction between elevated carbon dioxide and nitrogen nutrition: the physiological and molecular background. *Plant, Cell and Environment 22(6):583-621.*

This review first summarizes the numerous studies that have described the interaction between the nitrogen supply and the response of photosynthesis, metabolism and growth to elevated [CO2]. The initial stimulation of photosynthesis in elevated [CO2] is often followed by a decline of photosynthesis, that is typically accompanied by a decrease of ribulose-1,5- bisphosphate carboxylase/oxygenase (Rubisco), an accumulation of carbohydrate especially starch, and a decrease of the nitrogen concentration in the plant. These changes are particularly marked when the nitrogen supply is low, whereas when the nitrogen supply is adequate there is no acclimation of photosynthesis, no major decrease in the internal concentration of nitrogen or the levels of nitrogen metabolites, and growth is stimulated markedly. Second, emerging evidence is discussed that signals derived from nitrate and nitrogen metabolites such as glutamine act to regulate the expression of genes involved in nitrate and ammonium uptake and assimilation? organic acid synthesis and starch accumulation, to modulate the sugar-mediated repression of the expression of genes involved in photosynthesis, and to modulate whole plant events including shoot-root allocation, root architecture and flowering. Third, increased rates of growth in elevated [CO2] will require higher rates of inorganic nitrogen uptake and assimilation. Recent evidence is discussed that an increased supply of sugars can increase the rates of nitrate and ammonium uptake and assimilation, the synthesis of organic acid accepters, and the synthesis of amino acids. Fourth, interpretation of experiments in elevated [CO2] requires that the nitrogen status of the plants is monitored, The suitability of different criteria to assess the plant nitrogen status is critically discussed. Finally the review returns to experiments with elevated [CO2] and discusses the following topics: is, and if so how, are nitrate and ammonium uptake and metabolism stimulated in elevated [CO2], and does the result depend on the nitrogen supply? Is acclimation of photosynthesis the result of sugar- mediated repression of gene expression, end-product feedback of photosynthesis, nitrogen-induced senescence, or ontogenetic drift? Is the accumulation of starch a passive response to increased carbohydrate formation, or is it triggered by changes in the nutrient status? How do changes in sugar production and inorganic nitrogen assimilation interact in different conditions and at different stages of the life history to determine the response of whole plant growth and allocation to elevated [CO2]?

KEYWORDS: ADP-GLUCOSE PYROPHOSPHORYLASE, ARABIDOPSIS-THALIANA L, ATMOSPHERIC CO2 ENRICHMENT, CALVIN CYCLE ENZYMES, DEPENDENT GLUTAMATE SYNTHASE, NITRATE REDUCTASE-ACTIVITY, PHASEOLUS-VULGARIS L, RIBULOSE-1;5-BISPHOSPHATE CARBOXYLASE-OXYGENASE, SUCROSE PHOSPHATE SYNTHASE, TRANSGENIC TOBACCO PLANTS

2276

Stitt, M., W.P. Quick, U. Schurr, E.D. Schulze, S.R. Rodermel, and L. Bogorad. 1991. Decreased ribulose-1,5-bisphosphate carboxylase-oxygenase in transgenic tobacco transformed with antisense rbcs .2. Flux- control coefficients for photosynthesis in varying light, CO2, and air humidity. *Planta 183(4):555-566.*

Transgenic tobacco (Nicotiana tabacum L.) plants transformed with 'antisense' rbcS to produce a series of plants with a progressive decrease in the amount of ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) have been used to investigate the contribution of Rubsico to the control of photosynthesis at different irradiance, CO2 concentrations and vapour-pressure deficits. Assimilation rates, transpiration, the internal CO2 concentration and chlorophyll fluorescence were measured in each plant. (i) The flux-control coefficient of Rubisco was estimated from the slope of the plot of Rubisco content versus assimilation rate. The flux-control coefficient had a value of 0.8 or more in high irradiance, (1050 mumol m-2 s-1), low-vapour pressure deficit (4 mbar) and ambient CO2 (350-mu-bar). Control was marginal in enhanced CO2 (450-mu-bar) or low light (310 mumol m-2 s-1) and was also decreased at high vapour- pressure deficit (17 mbar). No control was exerted in 5% CO2. (ii) The flux-control coefficients of Rubisco were compared with the fractional demand placed on the calculated available Rubisco capacity. Only a marginal control on photosynthetic flux is exerted by Rubisco until over 50% of the available capacity is being used. Control increases as utilisation rises to 80%, and approaches unity (i.e. strict limitation) when more than 80% of the available capacity is being used. (iii) In low light, plants with reduced Rubisco have very high energy-dependent quenching of chlorophyll fluorescence (qE) and a decreased apparent quantum yield. It is argued that Rubisco still exerts marginal control in these conditions because decreased Rubisco leads to increased thylakoid energisation and high-energy dependent dissipation of light energy, and lower light-harvesting efficiency. (iv) The flux-control coefficient of stomata for photosynthesis was calculated from the flux-control coefficient of Rubisco and the internal CO2 concentration, by applying the connectivity theorem. Control by the stomata varies between zero and about 0.25. It is increased by increased irradiance, decreased CO2 or decreased vapour-pressure deficit. (v) Photosynthetic oscillations in saturating irradiance and CO2 are suppressed in decreased- activity transformants before the steady-state rate of photosynthesis is affected. This provides direct evidence that these oscillations reveal the presence of "excess" Rubisco. (vi) Comparison of the flux-control coefficients of Rubisco with mechanistic models of photosynthesis provides direct support for the reliability of these models in conditions where Rubisco has a flux-control coefficient approach unity (i.e. "limits" photosynthesis), but also indicates that these models are less useful in conditions where control is shared between Rubisco and other components of the photosynthetic apparatus.

KEYWORDS: C-3 PLANTS, FIXATION, LEAVES, LIMITATIONS, METABOLISM, NITROGEN, PHOSPHATE

2277

Stocker, R., C. Korner, B. Schmid, P.A. Niklaus, and P.W. Leadley. 1999. A field study of the effects of elevated CO2 and plant species diversity on ecosystem-level gas exchange in a planted calcareous grassland. *Global Change Biology 5(1):95-105.*

The relationship between plant species diversity and ecosystem CO2 and water vapour fluxes was investigated for planted calcareous grassland communities composed of 5, 12, or 32 species assembled from the native plant species pool. These diversity manipulations were done in factorial combination with a CO2 enrichment experiment in order to investigate the degree to which ecosystem responses to elevated CO2 are altered by a loss of plant diversity. Ecosystem CO2 and H2O fluxes were measured over several 24-h periods during the 1994 and 1995 growing seasons. Ecosystem CO2 assimilation on a ground area basis decreased with decreasing plant diversity in the first year and this was related to a decline in above-ground plant biomass. In the second year, however, CO2 assimilation was not affected by diversity, and this corresponded to the disappearance of a diversity effect on above-ground biomass. Irrespective of diversity treatment, CO2 assimilation on a ground area basis was linearly related to peak aboveground biomass in both years. Elevated CO2 significantly increased ecosystem CO2 assimilation in both years with no interaction between diversity and CO2 treatment, and no corresponding increase in above-ground biomass. There were no significant effects of diversity on water vapour nux, which was measured only in the second year. There were indications of a small CO2 effect on

water vapour flux (3-9% lower at elevated CO2 depending on the light level). Our findings suggest that decreasing plant species diversity may substantially decrease ecosystem CO2 assimilation during the establishment of such planted calcareous grassland communities, but also suggest that this effect may not persist. In addition, we find no evidence that plant species diversity alters the response of ecosystem CO2 assimilation to elevated CO2.

KEYWORDS: ALTER, BIODIVERSITY, CARBON, ECOLOGY, PERFORMANCE, PRODUCTIVITY, STOMATAL RESPONSES, TRANSPIRATION

2278

Stocker, R., P.W. Leadley, and C. Korner. 1997. Carbon and water fluxes in a calcareous grassland under elevated CO2. *Functional Ecology 11(2):222-230.*

1. As part of a long-term study of the effects of elevated CO2 on biodiversity and ecosystem function in a calcareous grassland, we measured ecosystem carbon dioxide and water- vapour fluxes over 24-h periods during the 1994 and 1995 growing seasons. Data were used to derive CO2 and H2O gas- exchange response functions to quantum flux density (QFD). 2. The relative increase in net ecosystem CO2 flux (NEC) owing to CO2 enrichment increased as QFD rose. Daytime NEC at high QFD under elevated CO2 increased by 25% to 60%, with the greatest increases in the spring and after mowing in June when above-ground biomass was lowest. There was much less stimulation of NEC in early June and again in October when the canopy was fully developed. Night-time NEC was not significantly altered under elevated CO2. 3. Short-term reversal of CO2 concentrations between treatments after two seasons of CO2 exposure provided evidence for a 50% downward adjustment of NEC expressed per unit above-ground plant dry weight. However, when expressed on a land area basis, this difference disappeared because of a c. 20% increase in above-ground biomass under elevated CO2. 4. Ecosystem evapotranspiration (ET) was not significantly altered by elevated CO2 when averaged over all measurement dates and positions. However, ET was reduced 3-18% at high QFD in plots at the top of the slope at our study site. In summary, CO2 enrichment resulted in a large stimulation of ecosystem CO2 capture, especially during periods of a large demand of carbon in relationship to its supply, and resulted in a relatively small and variable effect on ecosystem water consumption.

KEYWORDS: ATMOSPHERIC CO2, CARBOXYLASE ACTIVITY, DIOXIDE, GAS-EXCHANGE, GROWTH, PARTIAL-PRESSURE, PHOTOSYNTHESIS, PLANT, RISING CO2, TUSSOCK TUNDRA

2279

Stocklin, J., and C. Korner. 1999. Interactive effects of elevated CO2, P availability and legume presence on calcareous grassland: results of a glasshouse experiment. *Functional Ecology 13(2):200-209.*

1, We investigated the interactive effects of elevated CO2, supply of phosphorus (P) and legume presence in model communities of calcareous grassland. Half of the communities contained six graminoids and eight nan-legume forb species, In the other half, four non-legume forbs were replaced by legumes. 2, Ecosystem responses. Above-ground phytomass (>5 cm) hardly responded to elevated CO2 alone. However, when P and legumes were combined. the CO2 effect on above-ground community phytomass in year two was a stimulation of 45% ($P < 0.001$). Below-ground community dry matter was stimulated by elevated CO2 alone by + 36% ($P < 0.01$), but was only + 20% ($P < 0.05$) when legumes were present and P was added, At the final (late season) harvest the mean effect of elevated CO2 on total above- and below-ground phytomass was + 23% ($P < 0.001$) and revealed no significant interactions among treatment combinations, because above- and belowground effects of CO2 enrichment had opposite directions. 3, Functional group responses. When legumes were absent, graminoids increased their total above- and below-ground phytomass in elevated CO2 by 60% ($P < 0.001$) but there was no increase when legumes were present. The response of forbs to CO2 was nor significant, irrespective of co-treatment. Legumes. however, were significantly stimulated by P supply and their CO2 response was much larger when P was added (+ 55%, $P < 0.01$ vs + 25%, NS). 4, Species responses. CO2 effects on species ranged from highly positive (+ 143%) to moderately negative (- 43%). 5, Our results demonstrate that the effect of CO2 enrichment in such natural grassland communities will be low on above-ground phytomass and largely below-ground if no additional nutrients are provided. N-2- fixing legumes appear to be crucial for the community response to elevated CO2 but legume responsiveness is largely controlled by P availability.

KEYWORDS: CARBON BALANCE, CHALK GRASSLAND, GROWTH-RESPONSE, LEVEL RESPONSES, LOLIUM-PERENNE L, NITROGEN-FIXATION, OLD-FIELD MICROCOSMS, PLANTS, STOMATAL RESPONSES, TRIFOLIUM-REPENS L

2280

Stocklin, J., P.W. Leadley, and C. Korner. 1997. Community and species level responses to elevate CO2 in designed calcareous grassland communities. *Acta Oecologica-International Journal of Ecology 18(3):241-248.*

We present a synthesis of two independent glasshouse experiments in which we investigated the short term response of model communities of calcareous grassland species to CO2- enrichment. Communities consisted of six species in the first study and of 14 species in-the second study. Communities were grown in containers filled with ca. 20 liters of natural soil. Total aboveground biomass production was increased by 14% (n.s., $p=0.21$) in the first study and by 8.5% ($p=0.03$) in the second study. This community level response was due to a significant stimulation of growth in 2 and 5 species, respectively. In each of the experiments, one species responded negatively to CO2-enrichment. The remaining species, including all legumes, remained unaffected by CO2-enrichment. Positive or negative responding species did not belong to specific functional groups, hence responses could not have been predicted from a priori knowledge of individual plant traits. Bromus erectus, which is the dominant species in calcareous grasslands of the Jura mountains, did not exhibit a CO2- response at the species level, but genotype-specific responses in this species varied significantly and included positive as well as negative responses. No such genotypic differentiation of CO2-response was observed in Fes tuca ovina. In the long term, we expect directional selection of positively responding genotypes and shifts in species composition to alter both population and community structure of calcareous grass lands - a conclusion that may also hold for other diverse plant communities.

KEYWORDS: ABANDONMENT, GROWTH, UNFERTILIZED MOWN MEADOWS

2281

Stocklin, J., K. Schweizer, and C. Korner. 1998. Effects of elevated CO2 and phosphorus addition on productivity and community composition of intact monoliths from calcareous grassland. *Oecologia 116(1-2):50-56.*

We investigated the effects of elevated CO2 (600 mu l 1(-1) vs 350 mu l 1(-1)) and phosphorus supply (1 g P m(-2) year(-1) vs unfertilized) on intact monoliths from species-rich calcareous grassland in a greenhouse. Aboveground community dry mass remained almost unaffected by elevated CO2 in the first year(+ 6%, n.s.), but was significantly stimulated by CO2 enrichment in year two (+26%. $P<0.01$). Among

functional groups, only graminoids contributed significantly to this increase. The effect of phosphorus alone on community biomass was small in both years and marginally significant only when analyzed with MANOVA (+6% in year one, +9% in year two, 0.1 greater than or equal to P > 0.05). Belowground biomass and stubble after two seasons were not different in elevated CO2 and when P was added. The small initial increase in aboveground community biomass under elevated CO2 is explained by the fact that some species, in particular Carex flacca, responded very positively right from the beginning, while others, especially the dominant Bromus erectus, responded negatively to CO2 enrichment. Shifts in community composition towards more responsive species explain the much larger CO2 response in the second year. These shifts, i.e., a decline in xerophytic elements (B. erectus) and an increase in mesophytic grasses and legumes occurred independently of treatments in all monoliths but were accelerated significantly by elevated CO2. The difference in average biomass production at elevated compared to ambient CO2 was higher when P was supplied (at the community level the CO2 response was enhanced from 20% to 33% when P was added, in graminoids from 17% to 27%, in legumes from 4% to 60%? and in C. flacca from 120% to 298% by year two). Based on observations in this and similar studies, we suggest that interactions between CO2 concentration, species presence, and nutrient availability will govern community responses to elevated CO2.

KEYWORDS: BIOMASS, CHALK GRASSLAND, ECOSYSTEMS, ENRICHMENT, GROWTH, LEVEL RESPONSES, PLANTS

2282

Stoffella, P.J., Y.C. Li, R.R. Pelosi, and A.M. Hamner. 1995. Citrus rootstock and carbon-dioxide enriched irrigation influence on seedling emergence, growth, and nutrient content. *Journal of Plant Nutrition 18(7):1439-1448.*

Seeds of Carrizo citrange (Citrus senensis (L.) Osb. X Poncirus trifolliata (L.), Cleopatra mandarin (C. reticulata Bianco), Sour orange (C. aurantium L.), and Rough lemon (C. limon (Burm f.) were sown in trays, irrigated without or with enriched Carbon dioxide (CO2) (1,362 mg L(-1)) and evaluated for seedling emergence, growth, and nutrient contents. Rough lemon had a faster rate and higher percent emergence than the other rootstocks. Carrizo citrange had thicker stem diameters and taller seedlings than other rootstocks. Cleopatra mandarin had the smallest seedling shoot and root weights and larger shoot:root ratios than Rough lemon and Sour orange. Carrizo citrange and Cleopatra mandarin had higher leaf chlorophyll-a and total chlorophyll content than Rough lemon or Sour orange. Carbon dioxide enriched irrigation had no effects on emergence or seedling growth variables except lower root weight. Lower media pH (6.90 versus 5.65), attributed to CO2 enriched irrigation, may have adversely affected root growth as compared to shoot characteristics. Leaf nutrient contents generally differed between rootstocks but were not affected by CO2 enriched water except for higher Zn and lower Mn contents. These results indicate that citrus seedling emergence, subsequent growth and leaf nutrient content differed between rootstocks but there are no beneficial effect from CO2 enriched irrigation.

KEYWORDS: CO2, FIELD, ROOT ZONE, TOMATO, WATER

2283

Storlie, C.A., and J.R. Heckman. 1996. Bell pepper yield response to carbonated irrigation water. *Journal of Plant Nutrition 19(10-11):1477-1484.*

Field studies were conducted to determine the influence of carbonated irrigation water on bell pepper (Capsicum annuum L.) yield, plant nutrient status, canopy carbon dioxide (CO2) concentration, and soil pH. Marketable yield, early yield, marketable fruit size distribution, and plant nutrient status were unaffected by carbonated irrigation water. Air CO2 concentration in the lowest portion of the canopy increased during irrigation events, but returned to the ambient CO2 concentration shortly after irrigation ceased. The effect of carbonated irrigation water on soil pH was marginal and unpredictable.

KEYWORDS: CO2, DIOXIDE ENRICHMENT, FIELD, FIXATION, GROWTH, POTATO PLANTS, ROOT ZONE, TOMATO

2284

Strain, B.R., and R.B. Thomas. 1992. Field-measurements of co2 enhancement and climate change in natural vegetation. *Water, Air, and Soil Pollution 64(1-2):45-60.*

It is generally assumed that healthy, natural ecosystems have the potential to sequester carbon under favorable environmental conditions. There is also evidence that CO2 acts as a plant fertilizer. It is of interest to know if these assumptions are valid and how natural systems might respond under future scenarios of CO2 increase and possible climate changes. Few measurements of the effects of CO2 and global climate change have been made on "natural" ecosystems under realistic field conditions. Most measurements have been conducted in the synthetic environments of totally controlled greenhouses and growth chambers. Several lines of evidence indicate that controlled environment studies using plants growing in pots induce experimental artifacts that reduce confidence in the use of results for prediction of future global responses. Open top chambers are being used in several autecological field studies in an attempt to obtain more realistic field environments. A few field microcosm studies have been completed and a system for the free air release of CO2 has been applied in cotton fields. Unfortunately, the requirement of large amounts of CO2 and financial restrictions have precluded the initiation of larger scale field studies in natural vegetation. This paper lists and summarizes the best field studies available but draws heavily on studies from artificial environments and conditions in an attempt to summarize knowledge of global environmental change on forests and other non-agricultural ecosystems. Finally the paper concludes that there is a need for the development and application of equipment for field measurements in several representative natural ecosystems and makes specific recommendation of the creation of a tropical research center.

KEYWORDS: ALASKAN TUNDRA, ATMOSPHERIC CARBON-DIOXIDE, DIFFERENT IRRADIANCE LEVELS, ELEVATED CO2, ESTUARINE MARSH, LIQUIDAMBAR- STYRACIFLUA, MINERAL NUTRITION, PINUS-TAEDA SEEDLINGS, TUSSOCK TUNDRA, WATER-STRESS

2285

Strand, M., D.A. Herms, M.P. Ayres, M.E. Kubiske, M.G. Kaufman, E.D. Walker, K.S. Pregitzer, and R.W. Merritt. 1999. Effects of atmospheric CO2, light availability and tree species on the quality of leaf detritus as a resource for treehole mosquitoes. *Oikos 84(2):277-283.*

Elevated CO2 could alter the productivity of heterotrophic aquatic ecosystems through effects on allochthonous litter inputs. The effects of atmospheric CO2 concentration, light availability to trees and tree species, on leaf detritus quality as a food resource for eastern treehole mosquitoes (Aedes triseriatus) were examined. Larvae were reared in laboratory microcosms (simulated treeholes) with naturally- senesced, abscised foliage from seedlings of red oak (Quercus rubra) and paper birch (Betula papyrifera) grown in ambient and elevated atmospheric CO2 environments. Elevated CO2 did not have significant effects on any measure of mosquito performance. In contrast, host species and light availability had dramatic effects on mosquito development time and survival; light availability had additional effects on adult size. Mosquito reproductive potential (+/- SE) averaged 8.4 +/- 1.5 females female(-1)

generation(-1) when litter input was from birch-sun leaves, but was 19.6 +/- 1.8 when the litter was from birch-shade leaves and 13.0 +/- 1.8 when from oak-sun leaves. Mosquito development time was nearly halved when the litter input was from oak-sun leaves versus birch-sun leaves, suggesting a potential for even greater demographic effects (e.g. two generations per year instead of one could yield a 20- fold increase in annual growth rate). Trophic transfer rates (mg insect detritivore g litter(-1) d(-1)) were 3-fold greater on birch-shade leaves than on birch-sun leaves. Changes in insolation and tree species composition can have important consequences for forest ecosystems, because of effects on litter quality that impact microbial saprobes and, ultimately, invertebrate detritivores.

KEYWORDS: AEDES-TRISERIATUS DIPTERA, BETULA-PENDULA ROTH, CARBON NUTRIENT BALANCE, CONDENSED TANNINS, DECOMPOSITION RATES, ELEVATED CO2, HOLE ECOSYSTEMS, LITTER QUALITY, SECONDARY METABOLITES, TERRESTRIAL ECOSYSTEMS

2286

Street-Perrott, F.A., Y.S. Huang, R.A. Perrott, G. Eglinton, P. Barker, L. BenKhelifa, D.D. Harkness, and D.O. Olago. 1997. Impact of lower atmospheric carbon dioxide on tropical mountain ecosystems. *Science 278(5342):1422-1426.*

Carbon-isotope values of bulk organic matter from high-altitude lakes on Mount Kenya and Mount Elgon, East Africa, were 10 to 14 per mil higher during glacial times than they are today. Compound-specific isotope analyses of leaf waxes and algal biomarkers show that organisms possessing CO2-concentrating mechanisms, including C-4 grasses and freshwater algae, were primarily responsible for this large increase. Carbon limitation due to lower ambient CO2 partial pressures had a significant impact on the distribution of forest on the tropical mountains, in addition to climate. Hence, tree line elevation should not be used to infer palaeotemperatures.

KEYWORDS: CO2, HYDROCARBONS, ICE CORE, ISOTOPE FRACTIONATION, ORGANIC-MATTER, PHYTOPLANKTON, PLANTS, QUATERNARY, SACRED-LAKE, SEDIMENTS

2287

Stronach, I.M., S.C. Clifford, A.D. Mohamed, P.R. Singletonjones, S.N. Azamali, and N.M.J. Crout. 1994. The effects of elevated carbon-dioxide, temperature and soil- moisture on the water-use of stands of groundnut (arachis- hypogaea L). *Journal of Experimental Botany 45(280):1633-1638.*

Stands of groundnut (Arachis hypogaea L. cv. Kadiri 3) were grown in controlled environment glasshouses at two mean air temperatures (28 degrees C and 32 degrees C), two atmospheric CO2 concentrations (375 ppmv and 700 ppmv) and two soil moisture treatments (irrigated weekly to field capacity or allowed to dry from 22 d after sowing). The transpiration equivalent, Omega(W) (g kPa kg(-1))-the product of the accumulated biomass/transpired water ratio and the saturation deficit-was calculated for all the treatments using aboveground harvest, root core and neutron probe measurements. Neither temperature nor soil moisture treatment was found to have an effect on Omega(W). Increased CO2 concentration raised Omega(W) from 6.21 +/- 0.30 to 7.67 +/- 0.29 g kPa kg(-1), an increase of 24% ($P < 0.005$). The importance of accounting for root material and pod composition when calculating Omega(W) was highlighted.

KEYWORDS: CO2, CROPS, USE EFFICIENCY

2288

Stryiewski, E.C., and D.A. Vieglais. 1995. Changes in leaf structure of 3 native florida plant-species grown in elevated co2 concentrations. *Plant Physiology 108(2):63.*

2289

Stuhlfauth, T., and H.P. Fock. 1990. Effect of whole season CO2 enrichment on the cultivation of a medicinal plant, digitalis-lanata. *Journal of Agronomy and Crop Science-Zeitschrift Fur Acker Und Pflanzenbau 164(3):168-173.*

2290

Stulen, I., and J. Denhertog. 1993. Root-growth and functioning under atmospheric co2 enrichment. *Vegetatio 104:99-115.*

This paper examines the extent to which atmospheric CO2 enrichment may influence growth of plant roots and function in terms of uptake of water and nutrients, and carbon allocation towards symbionts. It is concluded that changes in dry matter allocation greatly depend on the experimental conditions during the experiment, the growth phase of the plant, and its morphological characteristics. Under non-limiting conditions of water and nutrients for growth, dry matter partitioning to the root is not changed by CO2 enrichment. The increase in root/shoot ratio, frequently observed under limiting conditions of water and/or nutrients, enables the plant to explore a greater soil volume, and hence acquire more water and nutrients. However, more data on changes in dry matter allocation within the root due to atmospheric CO2 are needed. It is concluded that nitrogen fixation is favored by CO2 enrichment since nodule mass is increased, concomitant with an increase in root length. The papers available so far on the influence of CO2 enrichment on mycorrhizal functioning suggest that carbon allocation to the roots might be increased, but also here more experiments are needed.

KEYWORDS: CARBOHYDRATE CONTENT, CARBON-DIOXIDE ENRICHMENT, LIQUIDAMBAR- STYRACIFLUA, MINERAL NUTRITION, NUTRIENT CONCENTRATION, PINUS-TAEDA SEEDLINGS, PISUM-SATIVUM, PLANT GROWTH, SOYBEAN PLANTS, WATER-STRESS

2291

Stutte, G.W., N.C. Yorio, and R.M. Wheeler. 1996. Interacting effects of photoperiod and photosynthetic photon flux on net carbon assimilation and starch accumulation in potato leaves. *Journal of the American Society for Horticultural Science 121(2):264-268.*

The effect of photoperiod (PP) on net carbon assimilation rate (A(net)) and starch accumulation in newly mature canopy leaves of 'Norland) potato (Solanum tuberosum L.) was determined under high (412 proportional to mol .(m-)2 . s(-1)) and low (263 proportional to mol . m(-2). s(-1)) photosynthetic photon flux (PPF) conditions. The A(net) decreased from 13.9 to 11.6 and 9.3 mu mol . m(-2). s(-1), and leaf starch increased from 70 to 129 and 118 mg . g(-1) drymass (DM) as photoperiod (PP) was increased from 12/12 to 18/6, and 24/0, respectively. Longer PP had a greater effect with high PPF conditions than with low PPF treatments, with high PPF showing greater decline in A(net). Photoperiod did not affect either the CO2 compensation point (50 mu mol . mol(-1)) or CO2 saturation point (1100-1200 mu mol . mol(-1)) for A(net). These results show an apparent limit to the amount of starch that can be stored (approximate to 15% DM) in potato leaves. An apparent feedback mechanism exists for regulating A(net) under high PPF, high CO2 and long PP, but there was no correlation between A(net) and starch concentration in individual leaves. This suggests that maximum A(net) cannot be sustained with elevated CO2 conditions under long PP (greater than or equal to 12 hours) and high PPF

conditions. If a physiological limit exists for the fixation and transport of carbon, then increasing photoperiod and light intensity under high CO2 conditions Is not the most appropriate means to maximize the yield of potatoes.

KEYWORDS: GROWTH, LIFE SUPPORT SYSTEMS, LIGHT, PLANTS, SOLANUM TUBEROSUM L, SPACE

2292

Sukumar, R., H.S. Suresh, and R. Ramesh. 1995. Climate change and its impact on tropical montane ecosystems in southern India. *Journal of Biogeography 22(2-3):533-536.*

The montane regions (>2000 m MSL) of the Western Ghats in southern India feature stunted evergreen forests (C3 plant type) interspersed with extensive grasslands (C3 or C4 plant types). We have studied the vegetational history of this ecosystem in relation to climate change during the late Quaternary through stable-carbon isotope analysis of peat deposits as indicators of C3 or C4 plant types. Grasslands (of C4 type) were predominant during the last glacial maximum (20- 18 kyr sp) and again during 6-3.5 kyr sp, while forest and possibly C3 grassland expanded during the deglaciation, attaining their peak distribution at 10 kyr sp. The shift in C3 and C4 plant types seems related to changes in moisture and atmospheric CO2, with lower moisture and CO2 levels favouring the latter plant types. The oscillating climate and vegetation has influenced the structure and composition of the montane ecosystem. Plant diversity of the near-pristine montane forests is relatively lower than other comparable sites in the neotropics. The implications of global change on the tropical montane ecosystem, in particular the composition of the angiosperm and vertebrate communities, are discussed. In particular, an expansion of montane forest and replacement of C4 with C3 grassland can be expected. Human impact on the natural vegetation, such as conversion of grasslands to monoculture plantations of wattle and eucalypts may, however, interfere with natural succession caused by global climate change. Endemic mammals such as the Nilgiri tahr would face increased risk of extinction.

KEYWORDS: ICE-AGE, ISOTOPE EVIDENCE, KENYA, POLLEN, RECORD

2293

Sullivan, J.H. 1997. Effects of increasing UV-B radiation and atmospheric CO2 on photosynthesis and growth: Implications for terrestrial ecosystems. *Plant Ecology 128(1-2):194-206.*

Increases in UV-B radiation reaching the earth as a result of stratospheric ozone depletion will most likely accompany increases in atmospheric CO2 concentrations. Many studies have examined the effects of each factor independently, but few have evaluated the combined effects of both UV-B radiation and elevated CO2. In general the results of such studies have shown independent effects on growth or seed yield. Although interspecific variation is large, high levels of UV-B radiation tends to reduce plant growth in sensitive species, while CO2 enrichment tends to promote growth in most C-3 species. However, most previous studies have not looked at temporal effects or at the relationship between photosynthetic acclimation to CO2 and possible photosynthetic limitations imposed by UV-B radiation. Elevated CO2 may provide some protection against UV-B for some species. In contrast, UV-B radiation may limit the ability to exploit elevated CO2 in other species. Interactions between the effects of CO2 enrichment and UV-B radiation exposure have also been shown for biomass allocation. Effects on both biomass allocation and photosynthetic acclimation may be important to ecosystem structure in terms of seedling establishment, competition and reproductive output. Few studies have evaluated ecosystem processes such as decomposition or nutrient cycling. Interactive effects may be subtle and species specific but should not be ignored in the assessment of the potential impacts of increases in CO2 and W-B radiation on plants.

KEYWORDS: BARLEY PRIMARY LEAVES, ELEVATED CARBON-DIOXIDE, HERBIVORE INTERACTIONS, LEAF EXPANSION, LIQUIDAMBAR- STYRACIFLUA, OZONE DEPLETION, PHOTON FLUX- DENSITY, PINUS-TAEDA SEEDLINGS, PLANT COMPETITION, SCIRPUS- OLNEYI

2294

Sullivan, J.H., and A.H. Teramura. 1994. The effects of uv-b radiation on loblolly-pine .3. Interaction with co2 enhancement. *Plant, Cell and Environment 17(3):311-317.*

Projected depletions in the stratospheric ozone layer will result in increases in solar ultraviolet-B radiation (290- 320nm) reaching the earth's surface, These increases will likely occur in concert with other environmental changes such as increases in atmospheric carbon dioxide concentrations. Currently very little information is available on the effectiveness of UV-B radiation within a CO2-enriched atmosphere, and this is especially true for trees. Loblolly pine (Pinus taeda L.) seedlings were grown in a factorial experiment at the Duke University Phytotron with either 0, 8.8 or 13.8 kJ m(-2) of biologically effective UV-B radiation (UV- B-BE) The CO2 concentrations used were 350 and 650 mu mol mol(- 1). Measurements of chlorophyll fluorescence were made at 5- week intervals and photosynthetic oxygen evolution and leaf pigments were measured after 22 weeks, prior to harvest. The results of this study demonstrated a clear growth response to CO2 enrichment but neither photosynthetic capacity nor quantum efficiency were altered by CO2. The higher UV-B irradiance reduced total biomass by about 12% at both CO2 levels but biomass partitioning was altered by the interaction of CO2 and UV-B radiation. Dry matter was preferentially allocated to shoot components by UV-B radiation at 350 mu mol mol(-1) CO2 and towards root components at 650 mu mol mol(-1) CO2. These subtle effects on biomass allocation could be important in the future to seedling establishment and competitive interactions in natural as well as agricultural communities.

KEYWORDS: COMPETITION, ENRICHMENT, GROWN SEEDLINGS, HIGHER-PLANTS, IRRADIANCE, LIQUIDAMBAR- STYRACIFLUA, PHOTOSYNTHESIS, TAEDA SEEDLINGS, ULTRAVIOLET-B, VISIBLE-LIGHT

2295

Sultemeyer, D. 1997. Changes in the CO2 concentrating mechanism during the cell cycle in Dunaliella tertiolecta. *Botanica Acta 110(1):55-61.*

Synchronised cells of Dunaliella tertiolecta were used to investigate the expression of the CO2 concentrating mechanism over the cell cycle during growth in either ambient air (low Ci cells) or air enriched with 5% CO2 (high Ci cells). The cultures were analysed for extracellular carbonic anhydrase activity, affinity of photosynthesis for inorganic carbon (Ci) and the ability to accumulate Ci. In high Ci cells, carbonic anhydrase activity changed between 2-4 units mg(-1) Chl during the light-dark rhythm showing no clear periodicity. Similarly, the apparent affinity for Ci remained rather constant over the cell cycle. This was judged from the Ci concentrations required for half maximum rate of photosynthesis (K-1/2(Ci)) of 72-80 mu M. In the same cells the accumulation ratio of internal Ci versus external Ci ranged between 5 and 9.5 without a clear rhythm. In contrast, these parameters showed distinct periodical changes in synchronised low Ci cells. Carbonic anhydrase activity changed from 10 to 350 units mg(-1) Chl with maximum and minimum activities occurring in the middle and at the end of the light period, respectively. The K-1/2(Ci) values showed similar periodicity ranging between 13-36 mu M. In addition the

accumulation ratio increased up to 30 in the middle of illumination and decreased to its lowest level of 12 at the end of the light period. These results indicate the presence of a common step in regulating the induction of the measured parameters and that light is not an absolute requirement for the induction of the CO2 concentrating mechanism in synchronous low CO2 grown cells of Dunaliella tertiolecta.

KEYWORDS: ADAPTATION, BICARBONATE, CARBONIC-ANHYDRASE ACTIVITY, CARBOXYLASE, CHLAMYDOMONAS-REINHARDTII, CI CELLS, INDUCTION, INORGANIC CARBON, PHOTOSYNTHESIS, TRANSPORT

2296

Sultemeyer, D., and K.A. Rinast. 1996. The CO2 permeability of the plasma membrane of Chlamydomonas reinhardtii: Mass-spectrometric O-18-exchange measurements from (CO2)-C-13-O-18 in suspensions of carbonic anhydrase-loaded plasma-membrane vesicles. *Planta 200(3):358-368.*

The unicellular green alga Chlamydomonas reinhardtii possesses a CO2-concentrating mechanism. In order to measure the CO2 permeability coefficients of the plasma membranes (PMs), carbonic anhydrase (CA)-loaded vesicles were isolated from C. reinhardtii grown either in air enriched with 50 mL CO2 . L(-1) (high-C-i cells) or in ambient air (350 mu L CO2 . L(-1); low- C-i cells). Marker-enzyme measurements indicated less than 1% contamination with thylakoid and mitochondrial membranes, and that more than 90% of the PMs from high- and low-C-i cells were orientated right-side-out. The PMs appeared to be sealed as judged from the ability of vesicles to accumulate [C-14]acetate along a proton gradient for at least 10 min. Carbonic anhydrase-loaded PMs from high- and low-C-i cells of C. reinhardtii were used to measure the exchange of O-18 between doubly labelled CO2((CO2)-C-13-O-18) and H2O in stirred suspensions by mass spectrometry. Analysis of the kinetics of the O-18 depletion from (CO2)-C-13-O-18 in the external medium provides a powerful tool to study CO2 diffusion across the PM to the active site of CA which catalyses O-18 exchange only inside the vesicles but not in the external medium (Silverman et al., 1976, J Biol Chem 251: 4428-4435). The activity of CA within loaded PM vesicles was sufficient to speed-up the O-18 loss to H2O to 45360-128800 times the uncatalysed rate, depending on the efficiency of CA-loading and PM isolation. From the O-18-depletion kinetics performed at pH 7.3 and 7.8, CO2 permeability coefficients of 0.76 and 1.49 . 10(-3) cm . s(-1), respectively, were calculated for high- C-i cells. The corresponding values for low-C-i cells were 1.21 and 1.8 . 10(- 3)cm . s(-1). The implications of the similar and rather high CO2 permeability coefficients (low CO2 resistance) in high- and low-C-i cells for the CO2-concentrating mechanism of C. reinhardtii are discussed.

KEYWORDS: CHLOROPLASTS, CI CELLS, CONCENTRATING MECHANISM, CYANOBACTERIA, DIOXIDE, HCO3, IDENTIFICATION, INORGANIC CARBON, PHOTOSYNTHESIS, TRANSPORT

2297

Sulzman, E.W., K.A. Poiani, and T.G.F. Kittel. 1995. Modeling human-induced climatic-change - a summary for environmental managers. *Environmental Management 19(2):197-224.*

The rapid increase in atmospheric concentrations of greenhouse gases has caused concern because of their potential to alter the earth's radiation budget and disrupt current climate patterns. While there are many uncertainties associated with use of general circulation models (GCMs), GCMs are currently the best available technology to project changes in climate associated with elevated gas concentrations. Results indicate increases in global temperature and changes in global precipitation patterns are likely as a result of doubled CO2. GCMs are not reliable for use at the regional scale because local scale processes and geography are not taken into account. Comparison of results from five GCMs in three regions of the United States indicate high variability across regions and among models depending on season and climate variable. Statistical methods of scaling model output and nesting finer resolution models in global models are two techniques that may improve projections. Despite the many limitations in GCMs, they are useful tools to explore climate-earth system dynamics when used in conjunction with water resource and ecosystem models. A variety of water resource models showed significant alteration of regional hydrology when run with both GCM-generated and hypothetical climate scenarios, regardless of region or model complexity. Similarly, ecological models demonstrate the sensitivity of ecosystem production, nutrient dynamics, and distribution to changes in climate and CO2 levels. We recommend the use of GCM-based scenarios in conjunction with water resource and ecosystem models to guide environmental management and policy in a "no-regrets" framework or as part of a precautionary approach to natural resource protection.

KEYWORDS: ATMOSPHERIC CO2, CARBON-DIOXIDE CONCENTRATION, CHANGE IMPACTS, DELAWARE RIVER BASIN, ELEVATED CO2, GENERAL-CIRCULATION MODEL, GREAT-LAKES, THORNTHWAITE MOISTURE INDEX, TROPICAL DEFORESTATION, WATER-BALANCE

2298

Sun, J.D., G.E. Edwards, and T.W. Okita. 1999. Feedback inhibition of photosynthesis in rice measured by O-2 dependent transients. *Photosynthesis Research 59(2-3):187-200.*

The kinetic properties of photosynthesis (both transient and steady-state) were monitored using three non-invasive techniques to evaluate limitations on triose-phosphate (triose- P) conversion to carbohydrate in rice. These included analyzing the O-2 sensitivity of CO2 fixation and the assimilatory charge (AC) using gas exchange (estimate of the ribulose 1,5- bisphosphate pool) and measuring Photosystem II activity by chlorophyll fluorescence analysis under varying light, temperature and CO2 partial pressures. Photosynthesis was inhibited transiently upon switching from 20 to 2 kPa O-2 (reversed O-2 sensitivity), the degree of which was correlated with a terminal, steady-state suppression of low O-2 enhancement of photosynthesis. Under current ambient levels of CO2 and moderate to high light, the transient pattern was more obvious at 18 degrees C than at 26 degrees C while at 34 degrees C no transient response was observed. The transient inhibition at 18 degrees C ranged from 15% to 31% depending on the pre-measurement temperature. This pattern, symptomatic of feedback, was observed with increasing light and CO2 partial pressures with the degree of feedback decreasing from moderate (18 degrees C) up to high temperature (34 degrees C). Under feedback conditions, the rate of assimilation is shifted from being photorespiration limited to being triose-P utilization limited. Transitory changes in CO2 assimilation rates (A) under low O-2 indicative of feedback coincided with a transitory drop in assimilatory charge (AC) and inhibition of electron transport. In contrast to previous studies with many C-3 species, our studies indicate that rice shows susceptibility to feedback inhibition under moderate temperatures and current atmospheric levels of CO2.

KEYWORDS: CARBON METABOLISM, CHILLING INJURY, CHLOROPHYLL FLUORESCENCE, CO2 FIXATION, ELECTRON-TRANSPORT, LOW-TEMPERATURE, MATURE LEAVES, PHOTOSYSTEM, QUANTUM YIELD, VARIETAL DIFFERENCES

2299

Sung, F.J.M., and J.J. Chen. 1991. Gas-exchange rate and yield response of strawberry to carbon- dioxide enrichment. *Scientia Horticulturae 48(3-4):241-251.*

Short-term carbon dioxide (CO2) enrichment (1000-mu-l l-1 for 10 days), starting 2 weeks after initial bloom, enhanced the leaf CO2 exchange rate (CER) in rockwool-cultured strawberry (Fragaria x ananassa). CO2 enrichment throughout the fruiting period stimulated canopy CER, decreased chlorophyll and leaf protein loss, and enhanced fruit set and consequent fruit production.

KEYWORDS: ATMOSPHERES, ELEVATED CO2, GROWTH, PHOTOSYNTHESIS, PLANTS

2300
Suzuki, K. 1995. Phosphoglycolate phosphatase-deficient mutants of chlamydomonas-reinhardtii capable of growth under air. *Plant and Cell Physiology 36(1):95-100.*

Mutants deficient in phosphoglycolate phosphatase (PGPase) require elevated levels of CO2 for growth in the light and cannot grow when photorespiration occurs. Revertants, namely, double mutants capable of growth under air without restoration of the missing PGPase activity, might be expected to have secondary mutations that reduce or eliminate photorespiration. Nineteen revertants were selected from a culture of a PGPase- deficient mutant of Chlamydomonas reinhardtii (pgp-1-18-7F) after a second mutagenesis that involved treatment with 5-fluorodeoxyuridine and ethyl methanesulfonate. There were significant differences in the photosynthetic affinity for CO2 among revertant cells grown under 5% CO2. Eight revertants had five times higher photosynthetic affinity for CO2 than that of wild type 2137 cells grown under 5% CO2, resembling air-adapted wild-type cells, whereas four revertants had less than half the affinity for CO2 of the wild type. In all of the revertant cells with higher affinity grown in 5% CO2, the rates of photosynthesis under levels of CO2 below those in air were apparently higher than that of the wild type, whereas the rates under CO2-saturating conditions were lower than that of wild type, indicating that the efficiency of photosynthesis under air was significantly improved in these revertants. In addition, some revertants had a photosynthetic capacity and a growth rate higher than those of the wild type, without any increased photosynthetic affinity for CO2.

KEYWORDS: LIMITING CO2, PHOTORESPIRATORY MUTANT

2301
Suzuki, T., K. Ohtaguchi, and K. Koide. 1991. Effects of gas-flow rate of co2-enriched air, high co2 concentration, and anaerobic atmosphere on the growth of blue- green-alga anacystis-nidulans. *Journal of Chemical Engineering of Japan 24(6):797-798.*

2302
Svedang, M.U. 1992. Carbon-dioxide as a factor regulating the growth dynamics of juncus-bulbosus. *Aquatic Botany 42(3):231-240.*

The unusual growth pattern exhibited by Juncus bulbosus L. in a slightly acidic Swedish brown-water lake is due to a CO2 deficit. Decrease in growth rate during the summer can be avoided through CO2 addition in July when CO2 availability is low and epiphytes are thriving. Growth of J. bulbosus in the laboratory is stimulated by CO2 addition up to a concentration somewhat higher than in air (500 ppm). while higher CO2 pressure restrains growth. Root growth reflects the leaf biomass development, but is favoured by elevated CO2 levels even more than the leaves.

KEYWORDS: ACIDIFICATION, EUTROPHICATION, IMPACT, MACROPHYTE COMMUNITIES, PHOTOSYNTHESIS, PLANTS, SOFT WATERS

2303
Svensson, B.H., T.R. Christensen, E. Johansson, and M. Oquist. 1999. Interdecadal changes in CO2 and CH4 fluxes of a subarctic mire: Stordalen revisited after 20 years. *Oikos 85(1):22-30.*

The first subarctic wetland CO2 and CH4 Aux measurements were made at Stordalen in the beginning of the 1970s in connection with the IBP study. A return to this area in 1994-95 offered a unique opportunity to study possible interdecadal changes in northern wetland CO2 and CH4 emissions. Measurements of CO2 and CH4 fluxes were carried out in similar habitats as those investigated in 1974. The mire distribution of wet minerotrophic areas relative to the elevated ombrotrophic areas had changed dramatically over the twenty years. There were no significant differences between the CH4-flux in 1974. 1994, and 1995. However, the CO2 fluxes were significantly higher in 1995 than in 1974. Since differences in climatic conditions gave no cause for such a change it suggests a possible increase in decomposition rate to be due ro other factors. We suggest changes in vegetation composition, altered mineralization pathways and disintegration of permafrost as causes for the interdecadal increase in decomposition rates.

KEYWORDS: ALASKA, ARCTIC TUNDRA, CARBON DIOXIDE, CLIMATE CHANGE, METHANE EMISSIONS, PEAT, PEATLANDS, WETLANDS

2304
Swift, M.J., O. Andren, L. Brussaard, M. Briones, M.M. Couteaux, K. Ekschmitt, A. Kjoller, P. Loiseau, and P. Smith. 1998. Global change, soil biodiversity, and nitrogen cycling in terrestrial ecosystems: three case studies. *Global Change Biology 4(7):729-743.*

The relative contribution of different soil organism groups to nutrient cycling has been quantified for a number of ecosystems. Some functions, particularly within the N-cycle, are carried out by very specific organisms. Others, including those of decomposition and nutrient release from organic inputs are, however, mediated by a diverse group of bacteria, protozoa, fungi and invertebrate animals. Many authors have hypothesized that there is a high degree of equivalence and flexibility in function within this decomposer community and thence a substantial extent of redundancy in species richness and resilience in functional capacity. Three case studies are presented to examine the relationship between soil biodiversity and nitrogen cycling under global change in ecosystem types from three latitudes, i.e. tundra, temperate grassland and tropical rainforest. In all three ecosystems evidence exists for the potential impact of global change factors (temperature change, COP enrichment, land-use-change) on the composition and diversity of the soil community as well as on various aspects of the nitrogen and other cycles. There is, however, very little unequivocal evidence of direct causal linkage between species richness and nutrient cycling efficiency. Most of the changes detected are shifts in the influence of major functional groups of the soil biota (e.g. between microflora and fauna in decomposition). There seem to be few data, however, from which to judge the significance of changes in diversity within functional groups. Nonetheless the soil biota are hypothesized to be a sensitive link between plant detritus and the availability of nutrients to plant uptake. Any factors affecting the quantity or quality of plant detritus is likely to change this link. Rigorous experimentation on the relationships between soil species richness and the regulation or resilience of nutrient cycles under global change thus remains a high priority.

KEYWORDS: ATMOSPHERIC CO2, CARBON BALANCE, CO2-ENRICHMENT, COMMUNITY STRUCTURE, ELEVATED CO2, ENCHYTRAEIDAE OLIGOCHAETA, FERTILIZER APPLICATION, FOREST SOIL, MOWN GRASSLAND, TEMPERATE GRASS SWARD

2305

Sykes, M.T., I.C. Prentice, and W. Cramer. 1996. A bioclimatic model for the potential distributions of north European tree species under present and future climates. *Journal of Biogeography 23(2):203-233.*

A bioclimatic model based on physiological constraints to plant growth and regeneration is used here in an empirical way to describe the present natural distributions of northern Europe's major trees. Bioclimatic variables were computed from monthly means of temperature, precipitation and sunshine (%) interpolated to a 10' grid taking into account elevation. Minimum values of mean coldest-month temperature (T-c) and 'effective' growing degree days (GDD*) were fitted to species' range limits. GDD* is total annual growing degree days (GDD) minus GDD to budburst (GDD(o)). Each species was assigned to one of the chilling-response categories identified by Murray, Cannell & Smith (1989) to calculate GDD(o). Maximum T-c values were fitted to continental species' mild-winter limits and other deciduous species' warm-winter limits. Minimum values of relative growing-season moisture availability (alpha*) were estimated from silvics. Growth indices were calculated based on potential net assimilation (a quadratic in daily temperature) and alpha*. Growth can be rapid near a range limit, e.g. Picea abies (L.) Karsten in southern Sweden. Climate changes expected for CO2 doubling were projected on to the grid. Simulated distribution changes reflected interspecific differences in response to changing seasonality. Chilling responses proved important, e.g. the predicted range limit of Fagus sylvatica L. contracts in the west while expanding northwards as winters warm more than summers. Transient responses to climate change can be modelled using the same information provided that fundamental and realized niche limitations are distinguished-a caveat that underlines the dearth of experimental information on the climatic requirements for growth, and especially regeneration, of many important trees.

KEYWORDS: AMERICA, BUDBURST, FORESTS, FROST DAMAGE, PICEA-SITCHENSIS, RESPONSES, VEGETATION

2306

Syvertsen, J., and J.H. Graham. 1997. Carbon budgets of two Citrus sp. in response to elevated CO2 VA mycorrhizae and phosphorus status. *Plant Physiology 114(3):111.*

2307

Syvertsen, J.P., and J.H. Graham. 1999. Phosphorus supply and arbuscular mycorrhizas increase growth and net gas exchange responses of two Citrus spp. grown at elevated [CO2]. *Plant and Soil 208(2):209-219.*

We hypothesized that greater photosynthate supply at elevated [CO2] could compensate for increased below-ground C demands of arbuscular mycorrhizas. Therefore, we investigated plant growth, mineral nutrition, starch, and net gas exchange responses of two Citrus spp. to phosphorus (P) nutrition and mycorrhizas at elevated atmospheric [CO2]. Half of the seedlings of sour orange (C. aurantium L.) and `Ridge Pineapple' sweet orange (C. sinensis L. Osbeck) were inoculated with the arbuscular mycorrhizal (AM) fungus, Glomus intraradices Schenck and Smith and half were non-mycorrhizal (NM). Plants were grown at ambient or 2X ambient [CO2] in unshaded greenhouses for 11 weeks and fertilized daily with nutrient solution either without added P or with 2 mM P in a low-P soil. High P supply reduced AM colonization whereas elevated [CO2] counteracted the depressive effect of P on intraradical colonization and vesicle development. Seedlings grown at either elevated [CO2], high P or with G. intraradices had greater growth, net assimilation of CO2 (A(CO2)) in leaves, leaf water-use efficiency, leaf dry wt/area, leaf starch and carbon/nitrogen (C/N) ratio. Root/whole plant dry wt ratio was decreased by elevated [CO2], P, and AM colonization. Mycorrhizal seedlings had higher leaf-P status but lower leaf N and K concentrations than nonmycorrhizal seedlings which was due to growth dilution effects. Starch in fibrous roots was increased by elevated [CO2] but reduced by G. intraradices, especially at low-P supply. In fibrous roots, elevated [CO2] had no effect on C/N, but AM colonization decreased C/N in both Citrus spp. grown at low-P supply. Overall, there were no species differences in growth or A(CO2). Mycorrhizas did not increase plant growth at ambient [CO2]. At elevated [CO2], however, mycorrhizas stimulated growth at both P levels in sour orange, the more mycorrhiza-dependent species, but only at low- P in sweet orange, the less dependent species. At low-P and elevated [CO2], colonization by the AM fungus increased A(CO2) in both species but more so in sour orange than in sweet orange. Leaf P and root N concentrations were increased more and root starch level was decreased less by AM in sour orange than in sweet orange. Thus, the additional [CO2] availability to mycorrhizal plants increased CO2 assimilation, growth and nutrient uptake over that of NM plants especially in sour orange under P limitation.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, COLONIZATION, DEPENDENCY, ENRICHMENT, NITROGEN, PLANTAGO-LANCEOLATA, ROOT, SOUR ORANGE, TREES

2308

Szente, K., Z. Nagy, and Z. Tuba. 1998. Enhanced water use efficiency in dry loess grassland species grown at elevated air CO2 concentration. *Photosynthetica 35(4):637-640.*

Net CO2 assimilation rate (P-N), Stomatal conductance (g(s)), transpiration rate (E), and water use efficiency (WUE) in four perennial C-3 species (grasses: Dactylis glomerata, Festuca rupicola, dicots: Filipendula vulgaris, Salvia nemorosa) grown for 231 d in open-top chambers at ambient (CA, 350 mu mol mol(- 1)) or elevated (CE, 700 mu mol mol(-1)) CO2 concentrations were compared. When measured at CE, PN was significantly higher in CE plants of all four species than in the CA ones. The increase in P-N was less prominent in the two grasses than in the two dicots. The E was significantly higher in the CE-grass F. rupicola and CE-dicot F. vulgaris than in the CA plants. There was no change in E owing to CE in the other grass and dicot. The g(s) in F. vulgaris and F. rupicola increased, while there was a decrease in D. glomerata and no change in S. nemorosa. WUE increased in all species grown in CE: four- to five-fold in the dicots and less than two-fold in the grasses. The increase in WUE was primarily due to an increase in P-N and not to a decrease in E.

KEYWORDS: ATMOSPHERIC CO2, CARBON DIOXIDE, GAS-EXCHANGE, LONG-TERM, PHOTOSYNTHESIS, PLANTS, RESPONSES, STEPPE, STOMATAL CONDUCTANCE, TRANSPIRATION

2309

Tajiri, T. 1997. Studies on the cultivation and storage quality of bean sprouts .13. Growth and quality of thick bean sprouts cultivated with a CO2-enriched rotary method. *Journal of the Japanese Society for Food Science and Technology-Nippon Shokuhin Kagaku Kogaku Kaishi 44(4):332-339.*

Thick bean sprouts cultivated using a rotary box (rotary cultivation, RC) have a decreased yield and inferior quality, although the growth of sprouts from the beans is promoted and the nutrient content of the sprouts is improved(1)2)). Because exposure to high levels of carbon dioxide was useful for promoting the growth of the hypocotyl and increasing the quantity of harvested sprouts(3)), we combined the rotary box method with the CO2-enriched method(1)). Herein the usefulness of this combination method for improving the physical properties and the yield of bean sprouts by controlling hypocotyl growth were